U.S. NAVAL AIR DEVELOPMENT CENTER

Johnsville, Warminster, Pennsylvania

REPORT NO. NADC-AC-6806 18 MARCH 1968

LITERATURE SURVEY - VISUAL DATA RELEVANT TO AIRCRAFT CAMOUFLAGE

INTERIM REPORT
AIRTASK NO. A32-523-013/202-1/F020-03-01

P R E P A R E D B Y

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Aerospace Crew Equipment Department

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The psychological literature, relevant to developing military aircraft surface camouflage schemes to minimize visual detection, identification, and/or estimation ranges under varying conditions, is surveyed. The survey considers brightness, hue, saturation, spatial, temporal, and movement judgments and factors that affect attention. Special attention is given to prediction problems, specific areas requiring further research, and control and maintenance functions.

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CHAPTER I

INTRODUCTION

Research Program Goals

The present research program is oriented toward an operational problem--the need for an improved U. S. Navy aircraft camouflage system. In preliminary planning, it was concluded that this system would meet the needs of the Fleet, currently and in the near future, most efficiently if it were supported by a set of U. S. Navy aircraft surface camouflage schemes. This set of schemes should be related to the specific field conditions under which each of the schemes is appropriate.

The present research program was set up to obtain and organize the information needed for attaining this goal and, especially, to relate available information more closely to the operational problem, under the increased operational demands of the present and the near future.

To define the subject matter of this research program, the problem area of the surface camouflage of military aircraft can be conceptualized as involving two dimensions--functions and their requirements. First, military aircraft surface camouflage can be treated as including at least four types of human functions: observation, operation, control, and maintenance. Second, each of these functions can be treated as raising both engineering and human engineering requirements. Here, the operation function is of interest, chiefly, as the means whereby the aircraft target is taken through a complex environment. In these terms, the preliminary planning defined as the aircraft camouflage problem area in which additional information was needed as including the requirements involved in the observation of aircraft targets in complex operational environments. By their nature, these functions raise, chiefly, visual human engineering requirements. Moreover, in preliminary planning, it was concluded that the problem area segments where the needed information was available included the engineering and human engineering requirements involved in the control and maintenance of aircraft surface camouflage systems. Thus, the present report emphasizes the former. The latter subjects are briefly considered in Appendix A to provide some perspective in filling out the picture of the entire problem area.

Methods

Within the present research program, three methods are being pursued to obtain information concerning the human engineering requirements of aircraft surface camouflage schemes. These methods are discussed in Chapter II to explain the selection of particular methods for the purposes of this program. These methods include a literature survey, an informal field study, and informal laboratory studies.

Literature Survey--The Present Report

The literature survey is reported, here, as the first of two publications to be developed. This survey summarizes literature that is relevant to estimating the likelihood that a target will be seen on the basis of the target's surface characteristics and on the basis of other operational parameters that affect this prediction.

Since the final use of this survey is to assist in developing aircraft surface camouflage schemes, emphasis is upon target surface characteristics and surrounding conditions that reduce as much as is possible or practical the likelihood that an aircraft target will be visually detected. Also, the survey considers aircraft target characteristics that will create confusion in visual identification of an aircraft target or in visual estimation of various aircraft target characteristics. To provide perspective, literature is reviewed concerning target surface characteristics and surrounding conditions that affect target conspicuity. Some attention is also given to aircraft surface schemes for normal operations or for other purposes other than camouflage or conspicuity.

Since the present research program is oriented toward the development of a specific operational system, this literature survey emphasizes applicable studies and does not attempt to survey all studies in the fields of vision, optics, meteorology, and human engineering that are relevant only in broader theoretical, physiological, procedural, or other senses.

A thorough review of the psychological and physiological literature concerning visual data and theories is available in Vision and Visual Perception, edited by Graham (1965g). These and related fields, especially, the fields of optics and meteorology, are reviewed and theoretically developed by Middleton (1952) in Vision through the Atmosphere. Relevant human engineering data and systems research methods are summarized in handbook form in sources, such as Human Engineering Guide to Equipment Design, edited by Morgan, Cook, Chapanis, and Lund (1963) and in the

form of military specifications in such sources as Human Engineering Requirements for Bureau of Ships Systems and Equipment (Military Specification MIL-H-24848(SHIPS), of 15 November 1965).

At the outset, it was considered unlikely that this literature survey would find the "state of the art" so sophisticated that the conclusions would be clear and complete statements of the necessary and sufficient human engineering requirements for an aircraft surface camouflage system usable in the Fleet. Therefore, it was anticipated that a major portion of the conclusions of this review would consist of the formulation of the outstanding problems in available predictive statements.

Informal Field Study

An informal field study is to be carried out as a part of this research program. The primary aim of the field study will be to provide insights into practical operational problems and needs--insights found not to be obtainable through the literature survey.

In the time available, it will not be possible to conduct a representative survey of persons, squadron types, theaters, or even of problems. Instead, emphasis will be placed upon obtaining a maximum amount of advice from a few widely experienced, willing interviewees. The results of this interview study will not be reported separately. The results will, instead, be included in the second and final report of this program, probably as prefatory remarks.

Informal Laboratory Studies

Concurrently with the informal interview study, informal laboratory studies may be conducted. As with the interview study, the primary purpose of the laboratory studies will be to provide added information.

The laboratory studies will compare specific alternative aircraft surface camouflage schemes for particular U. S. Navy aircraft in a variety of simulated operational conditions. The criteria for these comparisons will be the effects of the camouflage schemes upon search, detection, identification, estimation, decision, and action by the observer with respect to the treated aircraft.

The laboratory studies will not be reported upon formally or separately. They will be included, like the results of the informal field study, in the preface of the final report.

Final Products and their Application

In addition to this literature survey as the first report of this research program, the second and final report is to be a draft of a handbook or manual describing proposed U. S. Navy aircraft surface camouflage schemes and organizing them as a system by describing their use in the Fleet for specific operational conditions. This is to be accompanied by a prototype model of a demonstration device to illustrate the relationship of the proposed schemes to their appropriate field conditions. From this point of view, this literature survey may be treated as a reference for users of the handbook and the demonstration device may be used by those who may wish to study, more fully, the proposed camouflage schemes under varying conditions.

CHAPTER II

COMPARISON OF METHODS FOR PREDICTING OPERATIONAL PERFORMANCE OF SYSTEMS

As stated in Chapter I, the present report attempts to draw together the relevant literature relating the problem area of military aircraft camouflage. Considerable emphasis is being placed, in the current program, on drawing conclusions and inferences from the existing literature. However, other methods will be used to yield supplementary information.

Also, this literature survey must consider, in forming conclusions and inferences, data produced by a wide variety of methods. A critical task of the survey is to evaluate these methods, *per se*, especially as to their usefulness in predicting the operational performance of systems, such as the aircraft surface camouflage system.

Chapter II therefore develops and applies criteria for comparing various methods of predicting system performance in the operational situation in which the system would be used.

Optimal Operational Systems

Our general goal is to develop an optimal U. S. Navy aircraft surface camouflage system. By "optimal" we mean a system which will perform better under operational conditions than will its possible alternatives.

The problem of valid prediction from the results of different system test methods to operational situations is crucial to all research. It is especially critical to military research. Garner (1950) has examined the predictive value of various methods. Also, he has discussed the necessarily associated criteria of practical value, which must be considered along with predictive value, to chose a method in a particular case. Then, he has applied these criteria to various methods that are used to evaluate proposed operational systems. Much of the following discussion is based on Garner's development (1950).

Criteria of a Method's Predictive and Practical Values

A particular method for predicting the operational performance of a system may be assessed according to two criteria: (1) generality of prediction, and (2) precision of prediction. These criteria of predictive values are inversely related in practice (Garner, 1950, p. 1).

When, as in military field situations, the operational situations to which prediction is being made is complex and has many demands upon it other than those imposed by research and development programs, criteria of the practical value of a particular method must be considered. Practical criteria concern the time, cost, and effort involved in obtaining information. The availability of the operational situation may also be a practical limitation. Personnel safety and equipment integrity are often important practical limitations.

Informal Methods

Of course, prediction is sometimes made on the basis of information obtained by casual observation or by other informal methods, such as authority, expert opinion, committee action, and the like. Especially under the pressure of emergency conditions, aspects of equipment items, equipment items, or entire systems have been designated for operational use on the basis of informal evaluation of alternatives.

Informal methods are of interest, in the present context, as a limiting case of emphasis upon criteria of practical value, such as time and availability. As military operations become increasingly complex, there is a corresponding decrease in the likelihood that informal methods for predicting field performance can be used successfully.

Operations Evaluation Method

Operations evaluation is the sort of information-gathering activity that is involved in the informal interview study planned as a part of the present research program. The term "operations evaluation" is suggested by Garner (1950, p. 1) to emphasize the differences between this method and the method of operational experimentation. The term "field study," for example, does not make clear the essential distinctions between the two methods. When the purpose of operations evaluation is to discover the relationships among various field conditions, then operations evaluation is equivalent to operational experimentation, to be discussed, below, and is, therefore, equivalent in predictive precision and generality.

The more usual types of information-gathering activity involved in operations evaluation are providing familiarity with operational conditions, seeking operational problems, and supplementing information gathered in other ways. It is in this last sense that the method is used in this research program in conceptualizing the informal interview study. These activities do not involve predicting the operational performance of systems, and, therefore, it is not relevant to discuss their precision or generality. However, they may affect the precision and/or generality of methods for which they are treated as preliminary or supplementary steps. For example, only in the field is it possible to acquire the familiarity with the operational situation that all applied research persons should have as a background to improve the fruitfulness of their research work. An outstanding example of the generality that results from thorough familiarity with the operational situation is the four volume report of D. R. E. Brown (1963).

Only in the field is it possible to identify critical problems and significant variables within these problems--their types, values, and interactions. Middleton (1952) has pointed out as an outstanding problem in the science of outdoor seeing, the lack of information as to the actual conditions under which the eyes are used in specific outdoor seeing situations (cf., pp. 228-229). If information is gathered in the field concerning the operational conditions under which a system will perform, then, it is possible to set up experiments of "systematic and representative design" (cf., Brunswik, 1947), that is, experiments of high generality and precision. In fields such as camouflage, too little effort has been placed upon this application of the method of operations evaluation. For example, in designing experiments to evaluate alternate proposed U. S. Navy aircraft surface camouflage schemes, serious attention should be given to finding out to what extent current camouflage schemes are actually used in the Fleet, to what extent authorized deviations are used, and to what extent and why requests for waivers are submitted.

Propaedeutic Methods

The familiarity with the problem area that may be gained by the method of operations evaluation is especially useful in complex problem areas in pointing out limitations that are imposed upon the operational performance of alternative systems by factors other than those that enter directly into a statement predicting system operational performance. It is often useful to study these ancilliary factors with methods that are appropriate to their nature; such methods are referred to, here, as propaedeutic methods.

In studying camouflage schemes for helicopters and observation aircraft for concealment against terrain backgrounds, a series of Marine Corps Development Center studies (cf., final report by Fairchild, 1958) emphasized field studies of the adequacy of alternative materials, methods, equipment, and personnel required to apply, repair, and remove the recommended surface camouflage schemes. Although experimental methods had been used to arrive at the recommendations for camouflage schemes, the usefulness of these schemes for concealment could be achieved in the field only if possibly serious maintenance problems did not restrict the application of the recommended schemes to the aircraft.

As an example from a different field, the study of Middleton (1952) treats the study of meteorological optics as propaedeutic to the prediction of vision through the atmosphere (cf., Chapter IX).

Experimental Method

Independently of the situation in which an experiment is conducted, whether in a laboratory or operational situation, an experiment may be defined as the measurement of the performance of men, machines, or man-machine combinations, under controlled conditions, with systematic variation and measurement of certain conditions so that system performance canbe stated as a function of the varied conditions (Garner, 1950, p. 3). It is essential in defining experimentation to make explicit that a criterion must be used to associate performance value with condition value (Graham, 1965e, pp. 61-62).

The dichotomy of laboratory versus operational experimentation may better be treated as a continuum. Any particular experiment is located at a point on this continuum that is appropriate to the problem area to which the experimental results are to be applied--whether a theoretical, procedural, or operational problem--with the selection of a point on the continuum being made both according to criteria of predictive value and according to criteria of practical value. Usually, in a research program whose aim is to gather information concerning an operational problem, it is necessary to use different types of experiment and, also, to supplement this information with other methods than the experimental.

For example, in a two year program to develop measures to increase or decrease the detectability of naval aircraft by visual means, a variety of studies were conducted by Siegel, Lanterman, Lazo, Gifford, and Provost (1966):

> The...studies represented an orderly progression from laboratory studies...to studies which attempted to cross validate the laboratory findings in a field visual range situation. (p. 1)

To these experimental methods, the report, mentioned above, added a simulator experiment.

Similarly, a wide variety of methods was used to select the maximally effective exterior surface treatment for visual aircraft collision avoidance (van Saun, 1960; Robinson, 1961). Laboratory studies, simulator studies, field observations, and flight tests were conducted.

As is implicit in these examples, selection of one or more types of experiment along the continuum from laboratory to operational experimental methods may be motivated by the need to collect by the device of using different experimental situations different types of information and/or by the desire to cross-validate experiments in relatively full operational situations. These two motivations are logically equivalent.

Operational comparisons of alternative systems permits highly precise prediction of the operational performance of the systems tested. However, as the results of this comparison are extrapolated to increasingly different systems and conditions, predictive generality weakens.

Laboratory comparisons of alternative systems can be designed to cover, not only the specific systems of interest and the specific conditions under which they will be used, but more broadly the dimensions thought to be involved in the systems, conditions, and performance criteria, with each dimension being tested over as wide a range as is likely to be covered in extrapolation of the results.

Practical rather than predictive values determine the preference shown in the literature for laboratory versus operational experimentation. Time of experimentation is less in the laboratory. The equipment, subjects, and conditions can be designed, scheduled, and simulated with as much flexibility as money and ingenuity allows. Laboratory costs are lower since full working complements of personnel and equipment are not required to activate the system. In the laboratory, maintenance down-time and break-down rates can be reduced; back-up systems can be provided more economically and more quickly. However, the decisive practical factor in preferring laboratory over operational experimentation is the difficulty of finding, controlling, systematically varying, and measuring condition variables in the field.

Middleton (1952, p. 95) describes as a "monumental task" the Roscommon tests (Blackwell, 1949) designed to transfer a laboratory experiment on visual range (Blackwell, 1946) to the field. He describes "the magnitude of the effort" needed to cover the ranges tested, "a series of remarkable improvisations" required to control the targets and their backgrounds, and the efforts to measure the atmospheric attenuation, involving photometry that was "difficult and ingenious."

Laboratory Experimentation

In the special case where prediction from laboratory experiments to operational performance is in relative magnitudes, the prediction can be expected to meet the criterion of generality. Relative magnitudes are more general than are absolute magnitudes. Relative magnitudes are less likely to be modified by changes in operational conditions, such as improvements in enemy techniques or loss of morale. Of course, the numerical values of relative magnitudes would change from the values derived in laboratory experimentation to the values obtained in operations. However, the change may be in the direction of safe prediction, that is, the relative magnitudes obtained in the laboratory may be biased toward being too small due to lower stress on the subjects in the laboratory. As stated by Garner (1950):

> A difference in the design of equipment can be relatively unimportant if the men operating the equipment have lots of time, and are not working under pressure. If, however, the men have to work under pressure, then the poor design will suffer more than the good design. (pp. 9-10)

When limiting magnitudes of operational performance are selected as the relevant measure for evaluating a system, extreme conditions may be required to produce the limiting performance values. If the extreme conditions cannot be achieved or are poorly controlled in the operational situation available at the time of experimentation, a laboratory experiment is preferable, since its predictive precision will be greater.

Even when the operational conditions to produce limiting performance can be achieved, the occurrence of the limiting performance may raise a practical value--a threat to personnel safety and/or equipment integrity. In such cases, laboratory experimentation is preferable to operational experimentation, regardless of other criteria.

Simulator Experimentation

Simulator experimentation is often preferred on practical criteria to overcome the difficulty of controlling relevant operational conditions. Complete "realism" may become overburdening according to practical criteria and is not necessary.

Operational Experimentation

Hexter (1944) has emphasized the need to evaluate suggested camouflage schemes in operational experiments.

> Visibility in the air is the result of so many variable factors that no conclusions should ever be accepted unless the suggested camouflage has been compared to standard camouflage under the conditions for which its use is recommended. (p. 1)
>
> Many of the opinions expressed on aircraft camouflage have not been checked in this manner and often are basically unsound. (p. 24)

A laboratory experiment cannot simulate all of the factors which affect actual performance. These factors may be many; they may interact; they may be unavailable, uncontrollable, or unmeasurable; they may not be known.

"Literature Survey" Method

A survey of relevant literature, such as is performed here, may serve as one step in a method for deriving estimates of the operational performance of alternative systems or subsystems. The following description of this method is, also, a description of the methodological orientation with which the present literature survey was undertaken.

The method in question, called here "the literature survey method," consists of deriving an estimate of system operational performance by taking the following steps (cf., Garner, 1950):

1. functional analysis of the system into its components

2. survey of the literature to obtain reported estimates of the operational performance of each component

3. weighting of each component's estimated operational performance according to specific criteria, such as importance to operations or frequency of occurrence

4. recombination of the system components according to their weighted estimated operational performance to derive an estimate of the operational performance of the system

5. comparison of steps (4) and (1) to refine step (1) and, in this manner, to begin a new cycle.

The outcome of the first four steps, starting with functional analysis, is a functional synthesis of the system. This result of the literature survey method first states the operational performance requirements of discrete components of the system and the relationships among the system components. It then states an estimation of the operational performance of the system, itself, in terms of the action of these components.

As was mentioned in Chapter I, it was not expected that the literature searched would allow for clear and complete statements of the requirements of a system and of its oomponents. Middleton (1952) has pointed out several areas where the literature is seriously inadequate for predicting the outdoor seeing of targets. Much earlier (1933), some of the same outstanding problems were pointed out by Boring. Thus, it was anticipated, in planning the present research program, that these four steps involving the literature survey method would point out needs for additional information; and the recycling would probably include informal field interview and laboratory studies.

Wulfeck, Weisz, and Raben (1958) have used the literature survey method to select five "basic curves" for predicting different types of visual performance in military aviation situations. They discuss the effect of outstanding problems upon the adequacy of the method, as follows:

> No one would pretend that applying the five basic sets of data will solve all visual problems that arise. It is entirely possible that applying the data will not completely solve any single problem. But, applying these data will give better problem solution than would be possible without them. Even more important, attempting to apply the data to any particular problem may identify those aspects of the problem for which the data are inadequate and thereby efficiently pin-point critical areas for basic or applied research to produce the data necessary for complete and optimal problem solution. (Wulfeck, Weisz, & Raben, 1958, p. 103)

In the simplest case, a literature survey is the only applicable method for considering those aspects of a system and/or its alternates that are inaccessible. When the alternate systems to be compared are so numerous and/or when the components involved are so complex that they cannot practically be represented in experimentation, the literature survey method provides a summary means of evaluation. As alternative systems and their conditions of application become increasingly numerous and complex, the literature survey may be aided by the use of such devices as nomograms or computer programs.

In terms of the predictive value of the literature survey method, experience has shown (Garner, 1950, pp. 10-11) that its prediction to absolute magnitudes of operational performance is low in precision but that its prediction to relative magnitudes of operational performance is high in generality, especially as to the direction of the relative magnitudes.

To increase precision, any significant component interactions must be explicitly entered into the predictive statement, the number of components entered in the statement must be kept small to avoid adding their separate errors, and any heavily weighted critical system components must be entered explicitly to avoid bias in extreme situations. Although this correction is often made by a constant "safety factor" (cf., Wulfeck, Weisz, & Raben, 1958, p. 127), the error and bias will be less if the correction is explicitly made. Of course, data must be available in the literature to provide means for making these corrections.

Form and Methodological Aims of this Literature Survey

From these considerations concerning methodology, it is concluded that the literature survey method is appropriate to deriving estimates for predicting the operational performance of systems--in this research program, a U. S. Navy aircraft surface camouflage system.

Such predictions can be expected to be general, if they are made in terms of the relative performance of alternative systems rather than in terms of absolute performance magnitudes. Operational experiments relevant to this specific research program are so few that any reported absolute magnitudes of system performance will be treated only as illustrations of the anticipated order of the magnitudes. For predictive statements, it would be necessary to conduct operational studies designed for high relevancy to this research problem in a developmental program carried out after the completion of this research program. Within this research program, the precision of prediction to operational performance will, therefore, not be emphasized.

Since the review considers relevant studies at any point along the continuum from laboratory to operational experimental settings, both average and limiting magnitudes of predicted operational performance of the camouflage system should be available from the literature.

Unfortunately, the relevant literature has consistently shown that this problem area is characterized by the presence of significant system component interactions, large numbers of relevant system components, and the importance of critical components in affecting system performance in certain situations--all of which can be expected to increase the error of estimates by any method.

With these reservations, the following chapters will follow the steps of the literature survey method, as described, above.

CHAPTER III

FUNCTIONAL ANALYSIS OF AIRCRAFT SURFACE SCHEMES, EMPHASIZING OBSERVATION AND OPERATION FUNCTIONS AND VISUAL HUMAN ENGINEERING REQUIREMENTS FOR THESE FUNCTIONS*

Prediction of the operational performance of aircraft camouflage surface systems requires as independent variables the system components of the aircraft surface as a target, its background, the illumination, and the atmosphere between the target and background, on the one hand, and the place where performance is measured, on the other.

In this research program, the dependent variable of operational performance is to be associated with these independent variables by means of an observer's visual response. Therefore, this visual response is a system component as the criterion variable that defines the function associating values of predicted operational performance with values of certain target, background, illumination, and atmosphere characteristics.

Operational Performance

As will be demonstrated in Chapter IX, it seems most pertinent to the operational problem to measure performance as a range. Since this range is defined by a visual response, it becomes, therefore, a visual range. This measure has been suggested by Middleton (1952) on the basis of previous research:

> We have used the term "visual range" to signify the distance that something can be seen; this term was introduced into English by M. G. Bennett (1930), possibly by way of translation of the German term Sichtweite, first used at least as long ago as 1924 (Koschmieder) with this meaning. (p. 3)

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* See Appendix A for a supplementary, although preliminary analysis, which emphasizes control and maintenance functions and the engineering and human engineering requirements for control and maintenance functions.

Visual Response

This use of a visual response as a criterion variable sets the prediction problem as within the field of the psychological and human engineering literature. Other criterion measures are, of course, possible, e.g., a photographic, radar, or optical meter response.

Thus, the literature on vision is reviewed according to the psychological dimension(s) to which the observer is instructed to respond, the type(s) of response required of the observer, and the level(s) of response taken to define the predictive statement. These aspects of a psychological visual event are discussed below. The physical dimensions and units in terms of which the stimulus is specified are, then, briefly described.

Dimensions

Boring described his doctrine of conscious dimensions in the classic, The Physical Dimensions of Consciousness, published in 1933. Titchener (1919) treated concepts, such as hue, as attributes of immediately given sensations. When, later, sensations were considered not to be given but to be as inferred, Boring substituted his concept of dimensions. This concept emphasizes that these sensory characteristics were scientifically derived (cf., Boring, 1933, p. 11). However, his defense of the concept of dimensions was practical, not theoretical:

> The doctrine of conscious dimensions...seems to me very important and the correct approach to the adequate description of mind. However, I am not willing to stress the doctrine...because I believe that categories of description, whether they be the psychological dimensions of quality and intensity or the physical dimensions of space, mass, and time, are scientifically arbitrary and temporary, matters of the convenience or economy of description. (Boring, 1933, p. xiii)

Psychological dimensions are used, here, in this sense--only as a scheme to classify the literature of vision. However, the position they are given in this report--the first order subdivision of literature in the psychological field of vision--is intended as a means of emphasizing that the observer is instructed in most visual experiments to respond only to one aspect of the

visual stimulus. Particularly in applying laboratory results to operational situations, it may be important to keep in mind that the results are specific to the dimension of the visual stimulus that the observer "sees" or was instructed to respond.

Boring (1933, p. 23) lists five sensory dimensions: intensity, quality, extensity, protensity, and attensity. Boring comments that attensity is not necessary. Here, simpler terms will be used, the terms will be treated as adjectives, and the dimension of attensity will be retained in very much modified form. Thus, the "dimensions" here are as follows: the brightness dimension; the hue and saturation dimensions; the spatial dimension; the temporal and movement dimensions; and the "dimension" of the observer's state, or the effects of various conditions, procedures, devices, and the like upon his performance in attending to visual stimuli. To the brightness dimension are arbitrarily assigned experiments in which dimension is not specified. In classifying experiments as to response dimension, certain related problems have been ignored: the observer's inability to follow instructions as to the dimension of the stimulus to which he is to respond, his failure to follow such instructions, and his self-instruction.

Types of Response

The visual system can be described generally as if measured at successive steps along the visual psychological and physiological system, e.g., at receptor, afferent, central, efferent, and motor stages.

> The response may be measured in many ways. It may be measured in terms of chemical or electrical activity of the eye produced by radiant energy, in terms of the sensations produced, in terms of perceptions produced or in terms of a muscular response of the observer to a visual stimulus. (Wulfeck, Weisz, & Raben, 1958, p. 2)

For the present purposes, photochemical or physiological measures are not immediately relevant nor are distinctions such as those between sensation and perception. The response types that are of interest, here, are search, detection, identification, estimation, decision, and action. Wulfeck, Weisz, and Raben (1958) relate these response types in the following example:

Suppose, for example, that a pilot is searching for enemy aircraft. He will not detect another aircraft unless it contrasts sufficiently with the sky or land it is seen against. He will not identify the aircraft unless it contrasts sufficiently with its background and unless its components contrast sufficiently with each other so that he can make out its shape and markings. He will not be able to judge its speed and course unless the contrast is sufficient so that he can continually see the aircraft as it changes position relative to its background. (p. 193)

The pilot's decision to take evasive action, to attack, or to take other action will depend on these preliminary responses as sources of information.

Search

Laboratory studies often instruct the subject as to the location in which the target will appear. In flight, this is rarely possible, although electronic aids, reconnaissance, intelligence information, and the like may provide some "instruction" that narrow the search task. Search may be defined, as follows:

> Search is the scanning performed in order to detect objects of possible interest... Therefore, search is the first phase of the search and identification procedure, and involves scanning. (Wulfeck, Weisz, and Raben, 1958, p. 186)

Detection

The primacy of detectability as the criterion for visual range in camouflage applications is illustrated by Hexter (1944), as follows:

> Suppose two (2) bombers are flying in formation on a clear day and, because of camouflage, one (1) bomber is less visible than the other. Suppose enemy fighters are cruising in the sky looking for the bombers and suddenly in the distance they sight them. Which bomber would be attacked!

In all probability the answer is: both bombers. Although the particular camouflage may have made one (1) bomber more difficult to see, this would not prevent it being attacked. The point is that when the enemy can see an airplane in the sky, the degree of visibility from that moment on is usually academic. Obviously camouflage is protection to an airplane in flight only when the airplane cannot be seen. After it has been seen, the camouflage is of little value. (p. 1)

Detection is sometimes characterized as a simple visual response or a sensation, as in the following:

> The simplest interpretation the visual part of the brain can make is that electromagnetic waves received by the eye are within the proper wave length band and have exceeded the absolute or difference threshold. In this case the object emitting the waves would be said to be visible. Such simple discriminations are said to be made at the sensory level and are called sensations. (Wulfeck, Weisz, and Raben, 1958, p. 1)

Identification

At a higher level of complexity of visual response, target identification or recognition may be used as a type of visual response to define the range at which a target can be "seen." The quotation, above, continues, as follows:

> The brain can make much more complicated interpretations beyond the sensory level. For example, it can combine sensations elicited by an object with learning or memory to make possible form recognition, color identification, and other complex events said to occur at the perceptual level and called perceptions. When an object is recognized or identified it is said to be perceptible. (Wulfeck, Weisz, and Raben, 1958, p. 1)

Middleton (1952) makes the following comment concerning the visual identification range as compared to the visual detection range:

> The subject of recognition is of course much more complicated than that of detection, and is in a very unsatisfactory state at the time of writing. We shall leave it to a future author, who will certainly be a psychologist of much distinction. (p. 93, footnote)

Estimation

If the visual identification range is modified from the observer's making of qualitative judgments to his making of quantitative judgments, the type of visual response is shifted from identification to estimation. Observer's making of estimations may be required concerning certain characteristics of an aircraft target--bearing, altitude, range, speed or acceleration, shape, hue, and so on. So-called confusion camouflage is designed to degrade these estimates and, therefore, may degrade the action taken on the basis of the information provided by the estimate (cf., Hexter, 1944, p. 22).

Decision and Action

The visual responses of search, detection, identification, and estimation may be treated as preliminaries providing information for a decision as to what action is appropriate. They can be measured only in that action is taken. This point is expressed by Wulfeck, Weisz, and Raben (1958):

> Following perception a decision may be made as to what to do about the object that has been perceived. A response may be initiated if one seems to be required --a series of nerve impulses to the muscles of the arms to move the control stick, for example. While decision and motor response are not part of the visual process, they are essential considerations in evaluating the visual system's effectiveness as a sensing and interpreting instrument, because only through them can the visual system's unusual sensitivity and acuity be fully utilized. (p. 104)

Levels

Aircraft surface camouflage schemes are designed to reduce, as far as is possible and practical, the range at which the aircraft will be seen. On the other hand, aircraft surface conspicuity schemes are designed to increase the visual range of the aircraft as far as is possible and practical. For other aircraft surface schemes, certain intermediate response levels may be specified as appropriate to certain aspects of normal operations.

Especially in military situations, very high or very low limits of response may be of interest or may be crucial in defining operational performance, as the following argues:

> Thinking in terms of the most valid type of prediction, it seems reasonable that the crucial factor in the operational situation is not the average performance but the peak performance--the performance that may be required only once in an engagement, but which determines whether the ship has succeeded or failed in its mission. (Garner, 1950, p. 12)

Interaction of Level, Type, and Dimension

In practice, aircraft surface schemes are defined, designed, and evaluated according to response, dimension, type, and level criteria. For example, conspicuity and arctic marking schemes are developed to produce long visual ranges for detecting hue. Aircraft collision avoidance schemes are referred to the criterion of a long range of visual detection and, more important, of estimation of hue, brightness, and/or pattern. Concealment camouflage schemes are assessed by comparison to a criterion visual response of a short detection range. Confusion camouflage schemes usually aim for short ranges where the response type is identification and/or estimation. For some camouflage schemes, confusion may be produced by a scheme which promotes a high response level which, however, is an incorrect identification and/or estimation. Pattern camouflage may use spatially patterned hue or brightness to make the target "look like" the background. In other cases, a pattern may be designed to make the target "look like" its bearing, etc., is other than it is. Here, the aim is to mislead as well as to confuse.

Visual Stimulus

In the typical vision experiment, the stimulus is specified according to the following dimensions: luminance, wavelength, colorimetric purity, size, distance, time, and optical characteristics (cf., Riggs, 1965a).

Luminance, Wavelength, and Colorimetric Purity

Boring (1933) points out that the description of the qualitative dimension as non-quantitative may express the scientific immaturity of the concept rather than a stable defining characteristic, since most scientific dimensions tend to be first qualitatively, and then, with further study, quantitatively defined.

In the present discussion, the common-sense approach will be taken that the sensed color can be described in terms of the stimulus correlates of luminance, wavelength, and colorimetric purity (cf., Graham, 1965c, p. 350). More detailed description of the results of varying stimulus characteristics are given in Graham's (1965b) discussion of "Color Mixture and Color Systems." Fried and Gibson (1961) have prepared a "Handbook of Color Notation Systems." This compilation seems useful for military applications, since it includes military color description systems, such as those in the following military documents:

Federal Standard 595, "Colors."

Air Force-Navy Aeronautical Bulletin 157, "Colors; List of Standard Aircraft Camouflage."

Air Force-Navy Aeronautical Bulletin 166, "Colors; List of Standard Aircraft Glossy."

This source provides transformation methods between systems for specifying the physical stimulus characteristics that produce brightness, hue, and saturation. For example, the Munsell system may be appropriate for use in specifying aircraft surface colors and the colors of their backgrounds. It has been used for background specification, on a large scale, by Chambers (1967).

Psychological brightness is usually measured as the luminance (B) of a stimulus surface, i. e., in terms of the value on a physical dimension which was associated with the psychological judgment. According to the level of the stimulus luminance being studied, the unit of luminance often used is the millilambert (mL) or the micromicrolambert($\mu\mu$L) (where one micromicrolambert equals 10^{-9} millilambert). The luminance unit of candles per square meter (candle/m^2) may be used in certain cases (where one millilambert equals ($\frac{10}{\pi}$) candle/m^2). When pupil size is controlled, is measured, or can be estimated, luminance may be transformed to retinal illumination, measured as trolands (the retinal illumination of one troland (uncorrected for the Stiles-Crawford effect) equals the luminance of one candle/m^2 or $\frac{\pi}{10}$ millilambert on a surface viewed through an artificial pupil of one square millimeter area (cf., Riggs, 1965, p. 37). To approximate the physical scale on a psychological brightness scale, the physical units are expressed in units of the common logarithm ($\log_{10}$).

Since brightness judgments are most often--and perhaps always--made as discriminations between the apparent brightness of a test stimulus and the apparent brightness of a comparison stimulus, brightness judgments may be expressed as the contrast between the luminance of the test stimulus surface and the comparison stimulus surface. For most applications, the test stimulus surface is referred to as the target surface, so its luminance is symbolized as "B_t." The comparison stimulus surface, in the present application, is often an extended background surrounding the target; therefore, it is referred to as "B_b." Thus, a discrimination which compares the target with the background in brightness may be expressed as the ratio:

$$\frac{B_t - B_b}{B_b} = \frac{\pm \Delta B_t}{B_b}$$

For targets darker than their background, this luminance contrast is negative, the maximum negative value for target-to-background luminance contrast is -1, for a "black" target. For targets brighter than their backgound, the luminance contrast is positive and is without limit in value:

> However, positive contrasts higher than 2 to 5 are unusual in the daytime unless the background is very dark or the target aircraft happens to reflect sunlight specularly. (Robinson, 1961, p. 7)

The target luminance at which the target is judged to be brighter than its background in a stated percentage of repeated judgments (usually 50%) is the threshold luminance. When the background is unilluminated or "dark," this threshold luminance is a measure of brightness sensitivity and may be referred to as "$\underline{\Delta} B_o$." For backgrounds of measurable luminance, the ratio $\underline{\Delta} B_o/B_b$ expresses threshold target-to-background luminance contrast. Middleton (1952, p. 87) refers to the absolute value of this ratio $\underline{\Delta} B_o/B_b$, as "$\underline{\epsilon}$." He emphasizes the importance of reporting the percentage of repeated judgments used to define "threshold"; perhaps, this value should be stated as a subscript, for example, "$\underline{\epsilon}_{50}$."

The eye responds to electromagnetic energy only within a very narrow band of wavelengths (λ), where wavelength is usually measured in units of millicrons (mμ). This band includes wavelengths from about 390 to about 760 mμ, although this range will vary with test conditions, especially with luminance.

The concept of colorimetric purity is described by Riggs (1965a). For simplicity, the simpler notion of spectral emission, transmission, or reflectance may be used. For example, the hue and saturation of a paint are described by the characteristics of the source which illuminates it, the energy for each wavelength within the visible range, and by the spectral reflectance of the paint, its selective reflectance for different portions of the visible spectrum.

Size, Distance, Time, and Optical Characteristics

These visual stimulus characteristics are interrelated and are alike in being best specified as relative to the observer. These points are illustrated to be developing measures for size and distance. The development of measures for time and optical characteristics of the stimulus is analogous.

Definition of the size and distance of a spatial dimension of the object being viewed may be stated: (1) directly (in inches, centimeters, miles, etc.), (2) as the visual angle (in radians or minutes of arc) subtended at the nodal point of the eye by the object, or (3) as the computed width (in millimeters or micra) of the image projected upon the retina. Visual acuity is a threshold concept:

> Visual acuity....is specified in terms of the minimum dimension of some critical aspects of a test object that a subject can correctly identify. Good visual acuity implies that a subject can discriminate fine detail... (Riggs, 1965b, p. 321)

The type of object used affects the psychological dimension that is probably involved and the measure that is appropriate to the results (cf., Riggs, 1965b, pp. 322-326). For bright objects seen against a dark background, the measure of visual acuity is not relevant, since these objects can always be seen, no matter how small the visual angle they subtend at the eye, if the intensity is raised high enough. This is the problem of the perception of point sources, which is discussed by Middleton (1952, pp. 90, 96-102) and which is not of interest, here, since this review deals with reflective surfaces rather than with self-luminous sources. For dark objects against a bright background and for objects of either positive or negative but low contrast with their backgrounds, however, the measure of visual acuity is appropriate, although the judgment involved appears to be of brightness discrimination rather than of spatial discrimination.

The form of the object viewed and the response required of the observer to define the threshold vary in different experiments and should be considered in applying these experiments to practical design problems. Observers may be asked to make a detection, identification, or estimation response to a point source (minimum visible acuity), to dots, squares, or lines (minimum perceptible acuity); to broken lines, gratings, or checkerboards (minimum separable acuity); to a Landolt ring (minimum distinguishable acuity); to an offset broken line (vernier acuity); to a moving object (dynamic acuity; and to a broken line offset as to distance (stereoscopic acuity).

For form, shape, or pattern discrimination, the stimuli must be named, since theories relating different types of form discrimination are not available. Therefore, generalizations from data obtained with one type of target to problems involving another type may not be warranted.

Target and Background

At the level of operations, the target and its background are the events of interest--the objects viewed. A major determinant of visual range is the target (Middleton, 1952, p. 3). For the present purposes, the target of interest is an aircraft which has been treated with a particular surface scheme, made up of reflecting finish materials. Therefore, the target of interest here must be considered both as to its over-all characteristics and as to its internal characteristics.

Considered as a whole, the aircraft may vary as to type, as to mission, and as to the general type of surface scheme applied to the surface. The details of the scheme will vary slightly for different types of aircraft, thus affecting the internal target characteristics which must be known to estimate the visual range of the aircraft. The general surface scheme will vary jointly for different missions and for different aircraft types, to the extent that specific types of aircraft are characteristically assigned to specific types of mission. The choice of general surface scheme will be based on whether the successful accomplishment of the mission or of a part of the mission that is critical to the entire mission depends on short, normal, or long visual range on the part of a potential observer, and whether the observer's critical task in deteriorating mission success is to search for, detect, identify, make estimations concerning, make decisions concerning, and/or take action concerning the aircraft.

Any aircraft mission includes certain phases, for example, take-off, climbout, navigation, letdown, landing, and taxiing. The mission may vary to include, for example, one or more of the following functions: training, testing, air-to-air refueling, formation flying, communications, reconnaissance, search, rescue, interception, bombardment, low altitude attack, and air attack. Each of these missions or parts of a mission may require specific consideration in terms of the type of target they present (cf., Dunlap & Associates, Inc., 1954, pp. 49-50; Wulfeck, Weisz, & Raben, 1958, pp. 4-5).

Special targets are inevitably associated with an aircraft. For example, contrails and ground shadows may be detectable at greater visual ranges than the aircraft, itself. In discussing analogous associated targets for sea surface craft--wakes and bow waves--D. R. E. Brown (1963) recommends special maneuvering measures as substitutes for surface measures that are ineffective for camouflaging these special associated targets.

Other specialized target details, for example, internal shadows, glare spots, diffuse boundaries, must be considered, especially in applying general exterior finish schemes to certain aircraft of specific types.

Backgrounds differ in their nature and in the effects upon them of environmental conditions, especially, meteorological, diurnal, and seasonal conditions. For example, backgrounds vary as to whether they are made up of the earth's surface, the sky at the horizon, the low sky near the horizon, the overhead sky, and so on. The overhead sky differs as to whether it is clear, thin overcast, overcast, or cloudy. For targets above the cloud layer and seen from above, these same variations in overcast become the background for the target as viewed from above. Sea backgrounds are affected by the state of the waves and the wind--they may be differentiated as wavy and windy or as smooth and calm. Terrain or land backgrounds are affected in a complex manner by meteorological conditions, seasonal conditions, and their nature (cf., Chambers, 1967).

Certain backgrounds may present special or critical visual problems, among these are the horizon background, uniform snow backgrounds under strong diffuse illumination, or "empty" backgrounds at altitude.

To estimate visual range the details of the aircraft target and its background must be considered according to the visual stimulus characteristics, discussed above. As a simplification, it may be possible to specify targets, backgrounds, and their respective details only as to reflectance, at least for situations where they are viewed at sufficient distance that their details are not perceived as extended and that their color is not perceived as having hue or saturation. McFarland (1953, p. 181) lists various backgrounds which are typically viewed from aircraft and gives their luminance (in millilamberts [mL]) when illuminated as they would be at near noon on a clear midsummer day. His data are as follows:

Background	Luminance (mL)*
Very clear sky	250
Average clear blue sky	500
Thin haze	1,000
Moderate haze	1,500
Thickly overcast	250
Medium cloud layer	1,000
Dense haze or thin cloud	2,000
Thick clouds, maximum	10,000
Sunlight cloud approaches	10,000
Deep clear water	500
Shallow inland water	1,000
Green woods	500
Grass and green crops	1,000
Barren soil	2,000
Snow, maximum	10,000

* Illuminated as at near noon on a clear midsummer day.

A considerable range of luminances are visible to the eye. The absolute threshold may be as low as 10^{-6} mL. The eye can respond to levels as high as 10^{10} mL, although a level of about 10^{9} mL, as produced by the sun's surface at noon, is damaging. Up to about 10^{-1} mL is considered the scotopic range--where the eye responds as a system of rod receptors; from about 10^{1} mL and up to about 10^{7} mL is considered the photopic range, where cone receptor function predominates. The middle range is considered a mixed, transition, or mesopic range.

At closer range, hue, saturation, and brightness of target and background details may be described in a simplified system, such as the Munsell color notation system, as has been done for large scale terrain backgrounds by Chambers (1967).

Again, at close range, size may be expressed as visual angle.

Illumination and Atmosphere

In the operational situation, visual range is determined, in part, by the amount and distribution of natural and artificial light (Middleton, 1952, p. 3) and the effect of optical properties of the atmosphere on the illumination as it reaches the observer. As the pilot maneuvers the aircraft through the spatial environment, complex geometric changes occur in the relative positions of the observer, aircraft target, its background, and the illumination. The earth or the horizontal as a reference adds a complicating factor to this geometry. The relative diffuseness of the illumination and of the target surface add another type of geometric factor.

For the simplest case of diffuse illumination, diffuse target surface reflectance and no earth reference, these geometric changes affect the effective amount of illumination in the line of sight between observer and the target with its background and, thus, affect the target and background luminance. In more complex cases, of illumination and/or target surface reflectance that varies with wavelength, the amount of luminance and the effective wavelengths from the target and its background to the observer is modified.

As the illumination becomes less diffuse and the target surface reflectance is more specular, special visual problems are produced. For example, visual problems are produced in special instances by glare from the aircraft surface, the illumination source, itself, from the glitter path of the illumination source in the sea, or from highly illuminated clouds below the aircraft.

In certain special cases, attempts at aircraft surface camouflage are futile. For example, when the aircraft target is between the observer and the illumination, the target is backlighted or silhouetted and, therefore, is highly visible regardless of its surface treatment. When the target is between the illumination and some extended reflecting background, such as the earth, ground shadows are so highly visible that they point out emphatically the presence of an aircraft target. Internal shadow patterns similarly produced on the aircraft as a background by structural parts of the aircraft are highly visible but may be modified somewhat by camouflage treatment. Internal shadow patterns, or other illumination or reflectance variations on the background, may provide such a range of background luminance that a single aircraft surface scheme cannot be determined that will be even roughly appropriate to all background variations.

When the earth or horizontal reference is included in this geometric scheme, the point of view with respect to the horizontal from the observer to the target and its background is an important variable affecting visual range. Different points of view should be considered, for example, straight up, slightly up, horizontal, slightly down, steeply overhead, or straight down.

Latitude, time of day, and season modify the illumination, the angle of elevation of the sun and moon, and, of course, the spectral and specular reflectance of the background. D. R. E. Brown (1963, Vol. 2, pp. 55-57) presents such values in graphical form, with a summary of the total range of natural illumination levels.

Altitude is an important variable generated by adding the earth as reference. This effect is chiefly the result of changes in the optical properties of the atmosphere with altitude. These optical properties of the atmosphere can be considered to be due to particles of many types, chiefly spherical liquid droplets of various sizes, present in fog, haze, clouds, rain, and even in apparently clear atmospheres.

In general, these droplets vary exponentially in number per unit area with altitude as do the gaseous molecules of the atmosphere, the change being negligible beyond about 50,000 feet. Festinger, Kelly, Orlansky, and Coakley (1948) computed visual acuity up to altitudes of 200,000 feet in all directions and found that visual acuity did not change above 50,000 feet, since the computed correction for atmospheric attenuation did not change significantly above this altitude. Measurements by Packer and Lock (1950) agree with theoretical computations by Tousey and Hulbert (1947). The latter study presents graphically daylight sky brightness and polarization values for different angles between the observation position and the sun.

However, both vertically and horizontally, the number per unit area of these droplets and of other particles is subject to many and local variations. Of special interest are particles due to smoke, dust, sea-salt nuclei, and industrial pollutants. These have been found to vary with altitude and with horizontal extent by different patterns than do the liquid droplets charactéristic of fogs and the like. Dukelman (1952), for example, has measured the horizontal attenuation of light by the atmosphere over cities, deserts, and sea and has found the distributions over cities to be less regular and more complex than over desert or sea.

For an atmosphere of a given attenuation factor, as distance increases, an illumination reflected from the target and its background toward the observer is affected so that the target-to-background contrast is reduced. First, the hue of the target and, then, its brightness reaches that of the background. At this point, the target is no longer visible, even though the target may be of sufficient size to be visible.

Measurement and Prediction of Environmental Factors

Fitts (1951) and Middleton (1958) treat as critical in predicting the visual range of a specific object the instrumentation necessary to measure the environmental parameters that may affect visual range. These parameters consist of atmospheric attenuation, external contrast of the aircraft with its background, and background luminance. Middleton concludes that currently available instrumentation is not sufficiently quick or accurate for field use.

The related problem of providing techniques for predicting future values of these environmental parameters from present measurements is, if anything, more critical and less well developed.

CHAPTER IV

REVIEW OF LITERATURE APPLICABLE TO PREDICTING THE BRIGHTNESS DIMENSION OF VISUAL RANGE

The present discussion of the brightness dimension includes experiments in which it can be assumed that the observer responded according to his judgment concerning a brightness aspect of the stimulus. From the general literature concerning the brightness dimension of response, only a few procedurally defined groups of experiments were considered--brightness discrimination or brightness contrast experiments, light and dark adaptation experiments, and spectral visibility experiments.

When an observer is asked to report on stimulus changes produced by varying the amount of light reflected by the stimulus, then, it is supposed that the sensory changes produced by the stimulus and upon which the observer is reported are those of brightness.

Boring discusses the theoretical confusions produced in attempting to relate this assumed psychological dimensions to others, especially, to assumed dimensions of hue and saturation. This confusion of the three dimensions of "color" is emphasized to define the neutral point for one dimension or for the three dimensions or their equivalents in combination. In practice, despite theoretical problems of definition, it is usually concluded that an intensitive sensory dimension for vision is demanded by common sense and by analogy with the other senses (Boring, 1933, p. 28). In this chapter, this common-sense point of view is taken--that an observer can, when so instructed, judge a stimulus in terms of its apparent brightness. The current status of the relationship of the many color theories to an increasing body of experimental studies involving brightness, hue, and saturation judgments is described in detail by Graham (1965a).

Detection of Matching Brightnesses

To produce a constant brightness effect, targets of different wavelengths must be presented at different luminances. When the constant brightness effect is the threshold taken in darkness, the resultant plot of the threshold luminance required to make the target just noticeably brighter than the unilluminated background as a function of the wavelength of the target is called the scotopic luminosity curve which pertains to peripheral function.

When the constant brightness effect is at a high level, the so-called photopic luminosity curve results which, because of the procedures used, represents color and foveal function. For this curve, the standard brightness is defined by a "white" stimulus area of fixed luminosity. A comparison stimulus is matched by the observer to be equal in brightness to the standard; on different trails the comparison stimulus is composed of different wavelengths, the band of wavelengths in each case being held to a narrow band, to the extent practical.

Figure 4-1 presents illustrative photopic and scotopic luminosity curves (Hecht and Hsia, 1945). These curves will vary for different conditions. The scotopic curve indicates that for rod or peripheral visual function, the least energy is required at wavelengths of about 510 mμ, the part of the spectrum that appears to be blue-green in hue. The photopic curve indicates that for foveal or color visual function, the minimum energy is required for wavelengths at about 555 mμ, the part of the spectrum that appears to be yellow inhue. Photopic data have been obtained by Gibson and Tyndall (1923); scotopic data, by Hecht and Williams (1922).

As the luminance of the standard "white" stimulus is decreased, the photopic luminosity curve generated shifts toward the scotopic curve, with a corresponding shift of the minimum from 555 to 510 mμ (Waters & Wright, 1943; Wright, 1946). This shift, called the Purkinje effect, is responsible for the observation made by Purkinje that luminance matches between samples of different hue made at one luminance level did not hold at other luminance levels.

The luminance difference between the scotopic and photopic curves at any wavelength is called the photochromatic interval and represents the distance over which, as a target is increased in luminance from threshold luminance, the target will appear to be colorless.

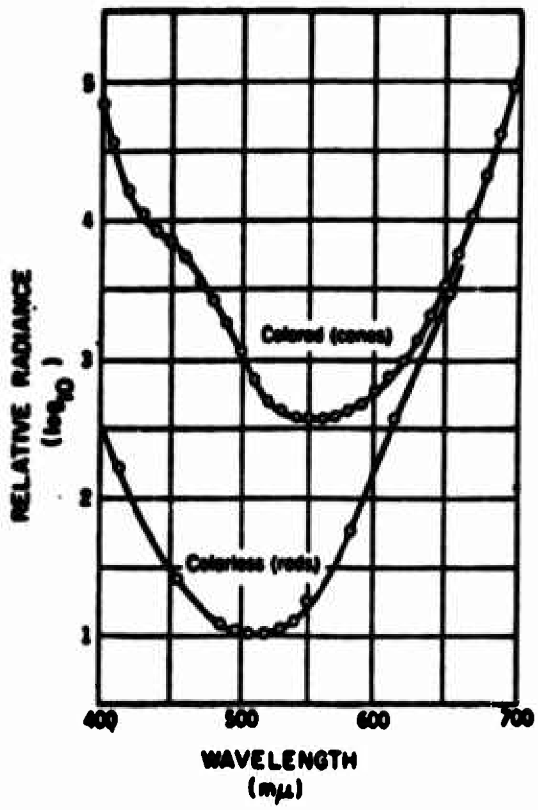

Figure 4-1. Relative radiance for rod and cone vision, at different wavelengths, positioned to show similar rod and cone thresholds at about 625 mμ (From Hecht & Hsia, 1945).

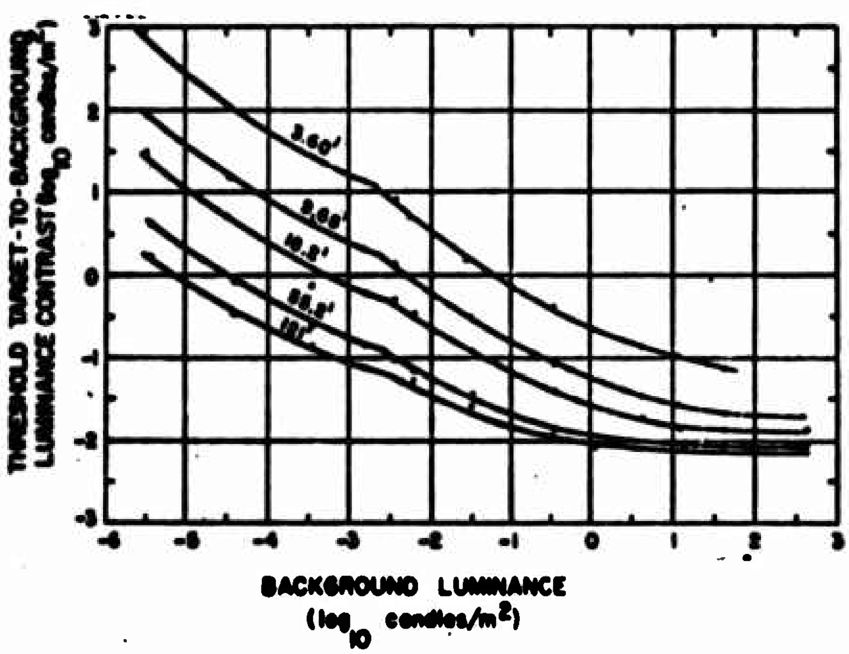

Figure 4-2. Just detectible target-to-background luminance contrast as a function of background luminance for different target visual angles (Data from Blackwell, 1946; as in Middleton, 1952, p. 88).

Detection of Just Noticeably Different Brightnesses

The principle stimulus variables which determine whether a target will be detectible as just noticeably brighter or dimmer than its background are the target luminance, the background luminance, the-target size, and the distance between the target and the observer. These physical variables are of primary importance. At least for simple and uniform targets, reflecting broad wavelength distribution of light, seen against extensive and uniform backgrounds, and viewed without restrictive conditions.

The most comprehensive study of the relationship of these variables and the study most readily applicable for the present purposes is described by Middleton (1952), as follows:

> The most elaborately organized research on the threshold of brightness-contrast, and the one involving the greatest number of observations, was that carried on during the Second World War at the Tiffany Foundation in the United States, and reported by Blackwell (1946).... Circular stimuli of various sizes ranging from 0.6 to 360 minutes in angular diameter were presented with various contrasts, positive and negative, on a large uniform background. The method of constant stimuli... was used throughout. The observers used both eyes, with no restriction of head movements or other special devices, and because the research was undertaken with the problems of vision through the atmosphere directly in mind, it is especially valuable for our purpose. (pp. 87-88)

Figure 4-2 summarizes this study's main results.

These data show thresholds for target-to-background luminance increments

$$\frac{+\Delta B_o}{B_b}$$

but data for corresponding decrements

$$\frac{-\Delta B_o}{B_b}$$

were obtained, with results as follows:

> Further curves... are given by Blackwell for stimuli darker than their background. In general they differ little from the results shown... except at low adaptation luminance and for large stimuli, where it is stated that the threshold is 20 per cent lower for the stimuli of negative contrast. This difference does not persist into the region of interest in daylight observations of visual range. (Middleton, 1952, p. 89)

The curves show a break into two limbs at about 2×10^{-3} candle/m^2. This break is often assumed to represent the anatomical and corresponding functional duplicity of the retina of the eye: rod retinal receptor function at low luminances; cone function at high luminances (cf., Hecht, 1937). This shift from rod to cone function with increasing background luminance represents a shift from parafoveal to foveal retinal location of the target, where the parafovea includes both cones and rods and the fovea includes only cones. The observers made this shift without special instructions, as will any normal observers for whom the retinal location of the target is not controlled by experimental techniques.

Concerning the effects of background luminance, threshold target-to-background brightness contrast decreases from nearly 1000 to less than .01 as background luminance increases by a factor of 100 million, over the range from very dark night to bright daylight, from below 10^{-5} to nearly 10^3 candle/m^2. The change in threshold contrast slows down or levels off only at about 10 to 10^2 candle/m^2, especially for targets larger than about 1°. The Weber law, restated by Fechner (1859), that $\Delta B_o/B_b$ is approximately constant, holds except for small targets and except for extreme values of B_b (Middleton, 1952, p. 87; Brown and Mueller, 1958, p. 215).

For targets larger than about 1°, $\Delta B_o/B_b$ is determined largely by background luminance. For targets smaller than about 1°, $\Delta B_o/B_b$ increases rapidly as target visual angle decreases, that is, $\Delta B_o/B_b$ is determined by both target visual angle and background luminance. Absolute values for ΔB_o as a function of target size cannot be determined, since different experiments vary considerably in procedure. In reviewing many experiments relating target size and background luminance to threshold target luminance increment (ΔB_o), Brown and Mueller (1965) reached the following conclusions:

These experiments suggest a gradual transition from one terminal condition (for small areas) where the product of area and threshold. . . is the determinant of the threshold, to the condition where the area of the test stimulus no longer influences the threshold. . . . Over limited ranges of the data, . . . a description of the relation between area of test stimulus and threshold would take the form of often-quoted laws of areal effects, such as L x A = C (Ricco's law) and L x A = C' (Piper's law), etc. (p. 212)

For three dimensional targets, such as aircraft, the orientation of the target with respect to the observer will change not only the apparent size, but also the apparent shape of the target (cf., Robinson, 1961, pp. 7-9). It is, therefore, necessary to have basic information on the effect of target shape upon brightness discrimination.

Lamar, Hecht, Shlaer, and Hendley (1947) determined $\Delta B_o/B_b$ for rectangular targets varying in length/width ratio from 2 to 200, varying in visual angle subtended at the eye from 0.5 to 800 square minutes of arc, and for two background luminances--56 and 9400 candles/m^2. For constant target area, they found little change in $\Delta B_o/B_b$ with length/width ratio for ratios of 7 or less, but considerable increase in $\Delta B_o/B_b$ as length/width ratio was increased from 20 to 200.

Since these data were obtained for monocular foveal vision and with an artificial pupil 2 mm. in diameter, their absolute values may not be transposable to situations allowing free binocular vision. Middleton suggests that data are needed for conditions more like those of the outdoor viewing of real targets (1952, p. 91). He points out the importance of studying real, frequently occurring targets, e.g., the extremely high length/width ratio of the horizon.

Brightness Discrimination as a Function of Target-to-Background Boundary Diffuseness

Targets with diffuse boundaries may occur in outdoor viewing due to atmospheric conditions, sharpness of focus of optical devices, or the nature of the target itself, occurring naturally or as a result of special treatment.

Middleton (1937) simulated various levels of the supposed diffusion of target boundaries due to fog by an artificial ogive boundary between the two halves of a $2^{o} \times 3^{o}$ rectangular field, seen with binocular vision at about 30 candles/m^2. He found that $\Delta B_o/B_b$ was not affected by the width of a diffuse boundary until the boundary was wider than about 7 minutes of arc and, beyond this, increased rapidly with the width of the diffuse boundary. He points out that the results of Kruithof (1950) are similar to his own. Since boundaries over 7 minutes of arc in width are not likely to occur in outdoor viewing, this effect is not important in predicting brightness discrimination. (cf., Middleton, 1952, pp. 92-93)

Diffusion of target boundaries was produced by defocusing the target by Ogle (1960, 1961a, b). In general, ΔB_o increased as the target boundary diffusion increased, with less increase for larger targets and for targets placed more peripherally with respect to the fovea.

For more complex target and background shapes, internal and external luminance contrast patterns become very complex. Surfaces with different reflectance characteristics and/or oriented at different aspects to the source present complex luminance patterns to the observer. Shape variations in three dimensions produce complex shadow patterns. Middleton (1952) states the problem, as follows:

> Practical fields of view are often very complicated; probably it is a safe generalization that they become simpler as the visual range decreases. There are certain recurring types of field that ought to be investigated... (p. 93)

A variety of studies are reviewed by Brown and Mueller (1965, pp. 220-223) in which the location of the "background" in the otherwise dark or unspecified surround and with respect to the target was varied, with some effects upon $\Delta B_o/B_b$. Blackwell and Bixel (1960, pp. 1-4) review studies of $\Delta B_o/B_b$ as a function of target and background non-uniformity, under simple conditions of non-uniformity that may be taken as representatives of military situations.

Obviously, theoretical formulations are needed to organize an infinitely complicated field. Kincaid, Blackwell, and Kristofferson (1958) suggested the following procedure:

> . . . the detectability of any target could be computed from its various elements of area in accordance with a contribution function, which weights each element of area in terms of its luminance and its separation from the center of the target. (Blackwell and Bixel, 1960, pp. 2-3)

This is an extension of an idea suggested by Graham, Brown, and Mote (1939). The study of Blackwell and Bixel (1960) is an attempt to test a short-cut generality, the assignment to a complex target of an effective contrast, comparable to the usual value of physical contrast in that it would faithfully predict the target's visibility under a variety of conditions. They conclude that their tests of the usefulness of this concept are promising but that: (1) other target-background complexes should be studied, (2) the generality of the concept of effective contrast should be checked as to its invariance under various parameters, (3) targets of military interest should be considered, and (4) the reasons why the concept "works" should be developed.

In the well-known Tiffany studies (Blackwell, 1946), an experiment was conducted with exposures long enough to be considered unlimited. In general, the effect of increasing exposure time during which the observers scanned for the target from six seconds to an unlimited duration is to lower $\underline{\Delta} B_o/B_b$ (Middleton, 1952, p. 89).

Variation in target exposure time from 0.002 to 0.500 second was studied by Graham and Kemp (1938) in terms of target exposure time as a parameter of the relationship between $\underline{\Delta} B_o/B_b$; their data are presented in Figure 4-3. In this experiment, $\underline{\Delta} B_o$ is presented as an increment in luminance over the background luminance. Under comparable experimental conditions, Herrick (1956) presented $\underline{\Delta} B_o$ as a decrement, with similar results. Keller (1941) has also performed a comparable experiment.

In general, these studies agree in the conclusion that increasing the target exposure time up to a critical exposure time shifts the curves lower on the ordinate, with the amount of the shift being approximately proportional to the change in target exposure time. For exposure times longer than the critical duration, there is little further shift. The critical duration is of the order of 0.10 seconds; it decreases as the background luminance increases. Below the critical duration, the product of $\underline{\Delta} B_o$ and the target exposure time is constant. (cf., Brown and Mueller, 1965, pp. 209-211)

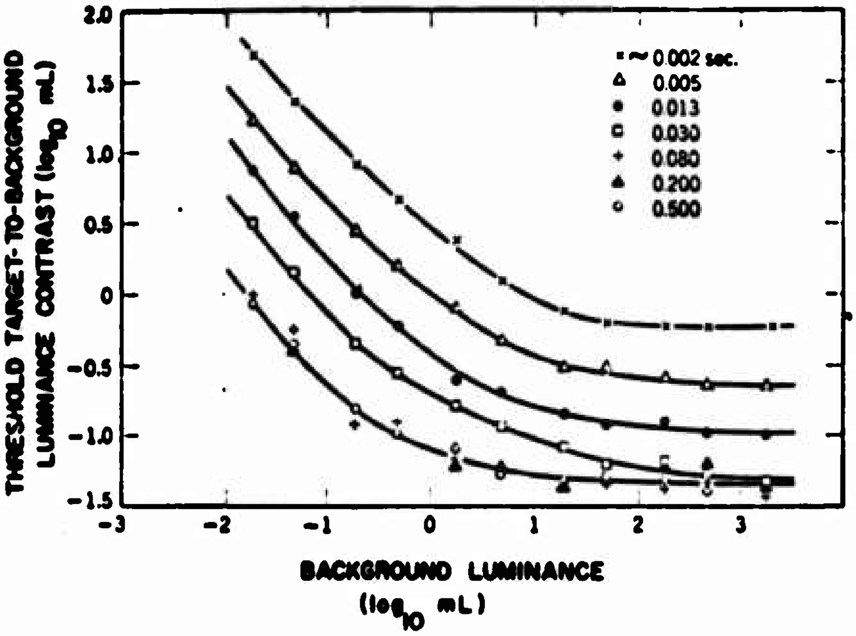

Figure 4-3. Just detectible target-to-background luminance contrast as a function of background luminance for different target exposure times (Data from Graham and Kemp, 1938; given in Brown & Mueller, 1965, p. 210).

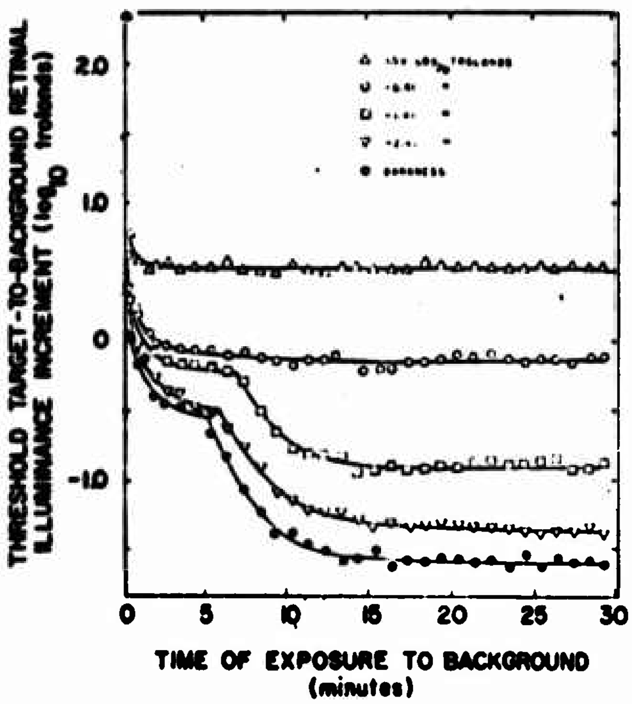

Figure 4-4. Just noticeable target-to-background retinal illuminance increment as a function of time exposure to the background (Data from Hattwick, 1954; given in Baker, 1955, p. 841).

In military situations, it often occurs that a person who must detect, identify, or make estimations concerning critical targets is exposed, because of the situation in which he operates, to wide ranges of luminances over short periods of time. For example, a jet pilot may climb in seconds through an overcast to high altitudes in which he must search for enemy aircraft against dark sky backgrounds or very bright backgrounds formed by the upper surfaces of clouds below him. The same man may be expected to check his flight instruments intermittently, to detect warnings, or read indications when the instrument background is in deep shadow due to the upward direction of illumination from the upper cloud surfaces under his aircraft.

With these changes in background luminance level and according to their temporal course, there is an accompanying more or less gradual adaptation of the sensitivity of the eye to the prevailing luminance. These sensitivity changes were first described in published data by Aubert (1865).

When the transition is to a relatively brighter level, the phenomenon called light adaptation occurs. When the shift is to a darker prevailing background luminance or to an unilluminated situation, there is a recovery in sensitivity with time in the dark up to a steady state of dark adaptation. That is, the threshold luminance required to detect a target decreases rapidly at first and less and less rapidly as time in the relatively dark situation continues. The lower curve in Figure 4-4 is a typical dark adaptation curve, that is a curve of ΔB_o as a function of time in the dark. For certain situations, the dark adaptation curve shows two limbs. The limb obtained in early dark times is attributed to dark adaptation of the cone visual receptor system, the "photopic system"; and the second, to dark adaptation of the rods, the "scotopic system." That any fairly extensive dark adaptation curves are two limbed was first shown by Kohlrausch (1922). Foveal, that is, cone dark adaptation was first reliably measured by Hecht (1921). In the photopic or cone limb of the dark adaptation curve, the target at minimally detectable luminances is seen as having a hue. In the second, scotopic, or rod dark adaptation limb, no hue is reported. At the region of transition from photopic to scotopic dark adaptation, the hue of the target may be reported to be gradually less and less saturated until the transition is completed; this region is often referred to as the mesopic region.

It should be noted that, in other than laboratory situations, the level of the background luminance encountered in transition from a brighter to a darker background luminance is rarely even approximately "dark" or unilluminated. Middleton (1958, p. 98) points out that perhaps the lowest background luminance encountered in military situations is that seen by a bow lookout on a ship on a moonless, overcast night, where the prevailing luminance may be of the order of 10^{-4} candles/m^2 (Middleton, 1958, p. 91). In many other respects, laboratory light and dark adaptation studies are not "realistic" as to simulating typical, critical, or all relevant field conditions in background luminances and, especially, in the temporal patterns of changing from one background luminance to another or of backgrounds of changing, as opposed to fixed luminance level. For each design problem, it may be necessary, therefore, to conduct field surveys to determine the time and luminance patterns of backgrounds and to decide, perhaps in preliminary or verification experiments, to what extent these field conditions must be simulated to provide valid and general prediction.

Adaptation to the dark and to various intermediate levels of background retinal illuminance, after complete adaptation to a brighter background, measured as the change in $\underline{\Delta} B_o$ as a function of time of exposure to the new background level, for parafoveal positioning of the stimuli, is shown in Figure 4-4 (Hattwick, 1954). The same study gives foveal data.

The complement to the experiment of Hattwick is that of Baker (1963), where $\underline{\Delta} B_o$ was determined as a function of time of exposure to various background retinal illuminances after exposure to a lower background retinal illuminance. For the limiting case, where the first background is dark and the second background is of various retinal illuminances, light adaptation data are obtained, such as that in Figure 4-5 (Baker, 1955, p. 842). The author summarizes these results, as follows:

> The classical measurements of light adaptation were made by Lohmann (1906-1907), in the first decade of this century, using the absolute threshold to assess visual sensitivity. . . . The threshold is low at first, showing high sensitivity, but the threshold rises continuously as sensitivity declines. . . .
>
> In view of Lohmann's results, we should now expect the ΔI to start low and rise during light adaptation, just as does the absolute threshold.

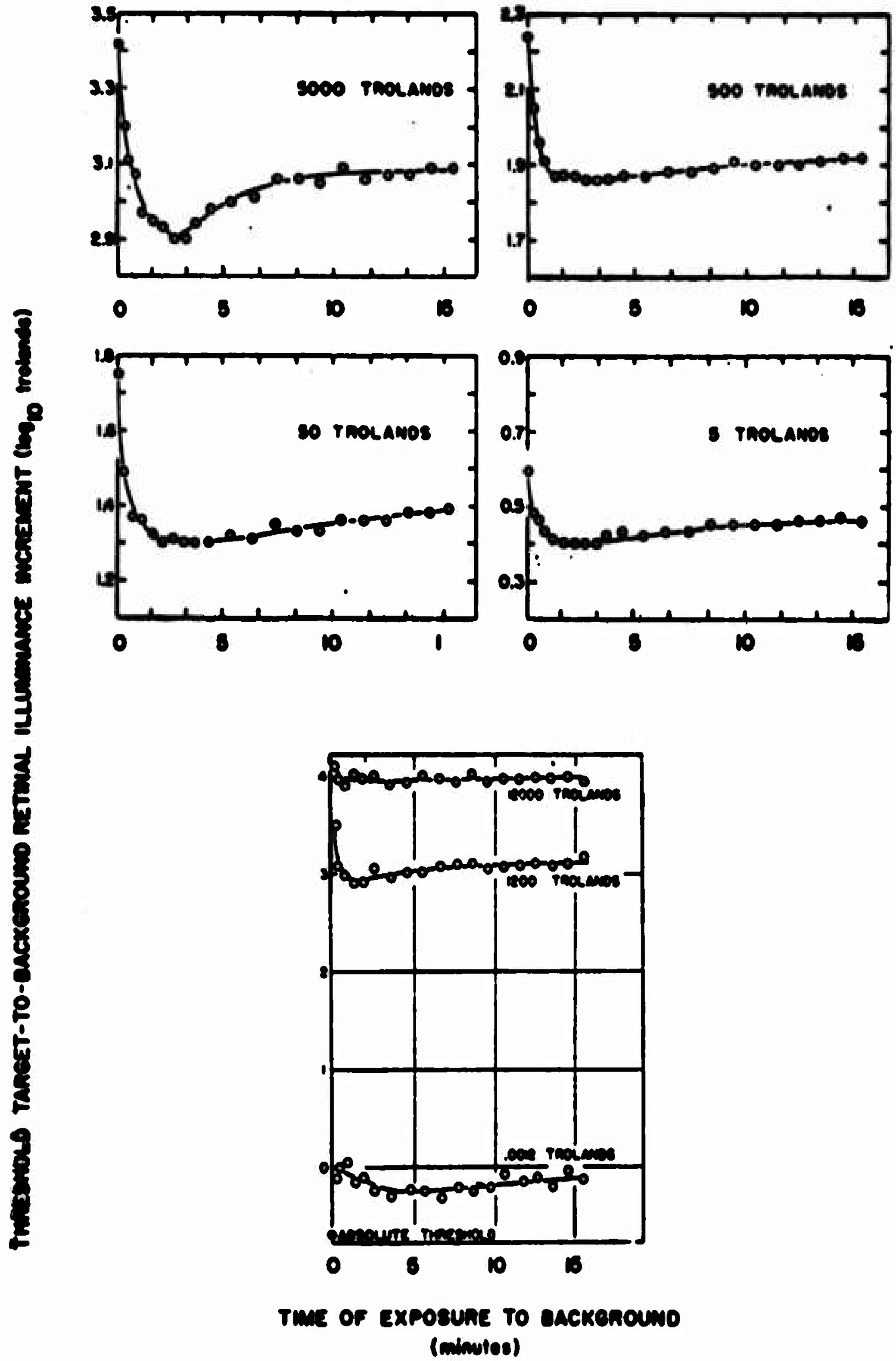

Figure 4-5. Just noticeable target-to-background retinal illuminance increment as a function of time of exposure to the background following full dark adaptation (Baker, 1955, p. 842).

> The expectation is not fulfilled (for the fovea) ....Instead of rising uniformly, the ΔI starts high, drops a bit, then rises again. Instead of changing a couple of log units, as would be expected from the absolute threshold data, the total change is never as much as one log unit. The total time required for the change is as expected, however, the change requires about 10 min...
>
> Similar results are obtained in the parafovea ....At the very highest adapting luminance, the effect appears to be reduced, but the lower levels show curve shapes like the foveal curves. (Baker, 1955, pp. 841-842)

The later increasing part of the brightness discrimination light adaptation curves is, Baker points out, superimpossible upon the comparable time section of light adaptation curves obtained by using the absolute threshold. The departure between the curves obtained by the absolute threshold method and the brightness discrimination method at early times in the light is explained by Baker as the effect of direct glare produced by the prevailing background. The glare effect is greater for higher prevailing background retinal illuminances and reduces during the first few minutes of exposure to the background.

This unexpected introduction of the "glare" situation helps to define, in terms of the well-understood techniques and data of light and dark adaptation, the situations in which military personnel experience glare. Glare is not only a source of temporarily lowered sensitivity but is also a source of discomfort. Holladay (1926, 1927) and Stiles and Crawford (1937) have studied the conditions under which glare occurs. Holladay explains glare by scattering of light in the ocular media, which produces a veiling. Baker (1955) gives an explanation involving high response frequency of optical system neurons because of their greater availability in the early stages of light adaptation. In any case, glare seems to produce a phenomena like that of masking in audition.

In military situations, it may be necessary to go from a relatively higher background luminance to a lower luminance. When the work at the lower background luminance requires cone function--fine visual detail, perception of color, etc.--adjustment of sensitivity to the lower luminance level can be hastened by reducing as much as possible the luminance and duration of the exposure.

Data on the effect of pre-adapting background luminance and duration upon dark adaptation have been obtained in a considerable number of studies for different conditions (cf., Winsor and Clark, 1936; Hecht, Haig, and Chase (1937); Wald and Clark (1937); Haig, 1941; Mote and Riopelle (1951, 1953); and Fletcher (1957).

When rod function is involved in the work at the lower background luminance, that is, for work such as gross visual acuity and brightness discrimination, rod dark adaptation can be made more rapid after leaving the brighter pre-adapting background luminance by using red illumination or red goggles for the pre-adapting period. Peskin and Bjornstad (1948) found that, for a pre-adapting background luminance of 1.1 mL, the color of the pre-adapting background affects the subsequent dark adaptation in that the time required to adapt was shorter for longer wavelengths, i.e., for violet, yellow, and red pre-exposure hues. White light pre-adaptation produced a result intermediate between those of the violet and yellow pre-adapting backgrounds. Hecht and Hsia (1945) compared dark adaptation after pre-adaptation with a white light (with very broad spectral composition but heavily weighted in short and medium wavelengths) with dark adaptation following exposure to a red light. The test stimulus used during dark adaptation was blue, 3° in diameter, and located 7° from the fovea. The recovery of sensitivity in the dark was more rapid for the red light. If the work during the pre-exposure period requires color discrimination, this device of using red work lights or filters during pre-adaptation cannot be applied (Morgan, Cook, Chapanis, & Lund, 1963, p. 78).

CHAPTER V

REVIEW OF LITERATURE APPLICABLE TO THE HUE AND SATURATION DIMENSIONS

In general, the sensory response dimension of quality (Boring, 1933, 1963) refers to the non-quantitative aspects of the dimension that seem most uniquely to characterize the dimension, in the case of vision, to "color." Since the term "color" includes in some contexts three visual response dimensions--brightness or lightness, hue, and saturation--the term "color" will be used, here, only in the most informal sense. For the more formal purposes of reviewing literature pertinent to the present problem, "hue" and/or "saturation" will be used, as appropriate.

The psychological dimension of brightness was discussed in Chapter IV. In the present chapter, the psychological dimensions of hue and saturation will be discussed.

The emphasis, in this review, upon experiments where the observer makes judgments of the hue of the stimulus should be compared to the broader range of experiments considered as within the field of color vision (Graham, 1965a, 1965b, 1965c). In understanding the visual response of color, it is necessary to consider situations where the observer responds to the color of the stimulus and situations to which his response is defined as on the hue or the saturation dimension.

Similarly, in selecting physical colors for applied problems, such as aircraft surfaces, the experiments may consider both responses to color and the response of color brightness, hue, and saturation. An example of this broad approach to a color design problem is that of Siegel, Lanterman, Lazo, Gifford, and Provost (1966) (cf., Siegel and Crain, 1960; Crain and Siegel, 1960; Siegel and Crain, 1961; Siegel, 1961; Federman and Siegel, 1962; and Siegel and Lanterman, 1963).

Hue Judgments

In line with the above comments, one of the more extensive and useful series of studies, that initiated by the study of the Eastman Kodak Company, in 1944, concerns the detection of color contrast. However, in most of these studies, the form of the visual response was appropriate to a visual acuity measure. Therefore, these studies are taken up in Chapter VI, in the review of studies using spatial characteristics of the visual response as criteria to study the effects upon visual response of various stimulus characteristics, including stimulus wavelength and colorimetric purity.

Detection of Just Noticeable Hues

Mapping of the retina with targets of various hues presented by perimetric or campimetric methods is equivalent to determining the minimum luminance required to produce a hue response for different retinal positions. Ferree and Rand (1919) used the latter method for four wavelengths and found that the retinal field for 522 mμ (green) was less, even at very high luminances, than the fields for 670 mμ (red), 581 mμ (yellow) and 468 mμ (blue). Rinde (1932) obtained comparable results.

Detection of Matching, Confused, or Just Noticeably Different Hues

Much of the difficulty in experimentation with hue and/or saturation visual responses is due to the Bezold-Brücke phenomenon--the finding that, to match a high intensity standard hue, the observer must modify the hue of a low intensity comparison stimulus (Purdy, 1937). For wavelengths of about 572 mμ (yellow), 503 mμ (green), and 478 mμ (blue), this effect is minimal. The extreme case is for 660 mμ (red), where a decrease in wavelength of about 34 mμ is required in a 10 troland stimulus to match it in hue to a 2000 troland stimulus. Figure 5-1 gives the contours obtained by Purdy (1937).

A hue contrast, $\underline{+}\underline{\Delta}\,\underline{\lambda}_o/\underline{\lambda}_b$, may be obtained by varying the hue of a comparison stimulus to adjust it to a just detectible increase or decrease in wavelength with respect to the wavelength of a reference, standard, or background stimulus. Jones (1917) made such hue comparisons between independently variable split halves of a circular field. He began at one end of the visible spectrum and set each successive standard at the comparison value determined on the last trial. In this manner, he concluded that the visible spectrum contains about 128 just noticeable differences of hue, some of only 1 mμ, most of about 3 mμ. His data are given in Figure 5-2. Different studies show considerable individual variation for different observers but agree as to the general form of the function (Steindler, 1906; Laurens and Hamilton, 1923).

The original use of yellow for conspicuity purposes was modified, in part, because yellow was confused with sea non-uniformities, such as the reflections of sunlight on the water. Similarly, a white target, although detectible and identifiable at as great a distance as yellow, is readily confused with white caps.

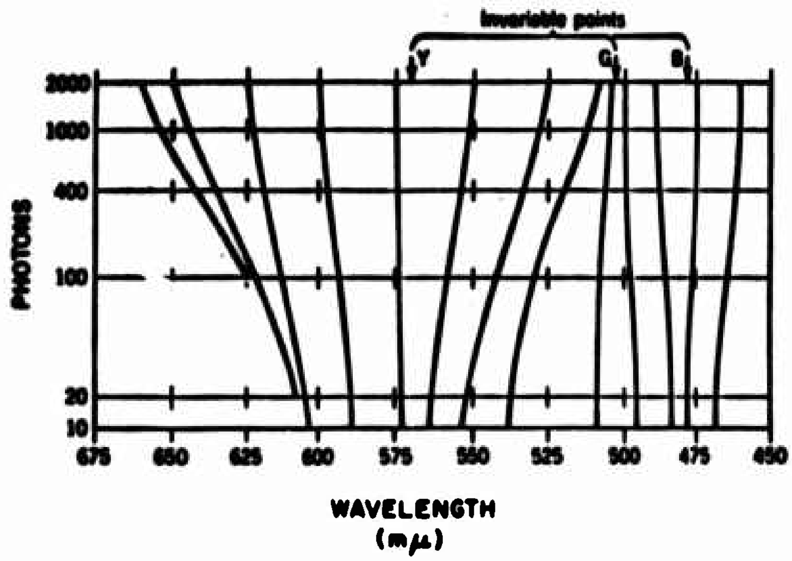

Figure 5-1. Contours for constant hue for varying retinal illuminance (in photons or trolands) (Data from Purdy, 1937; given in Geldard, 1953, p. 41).

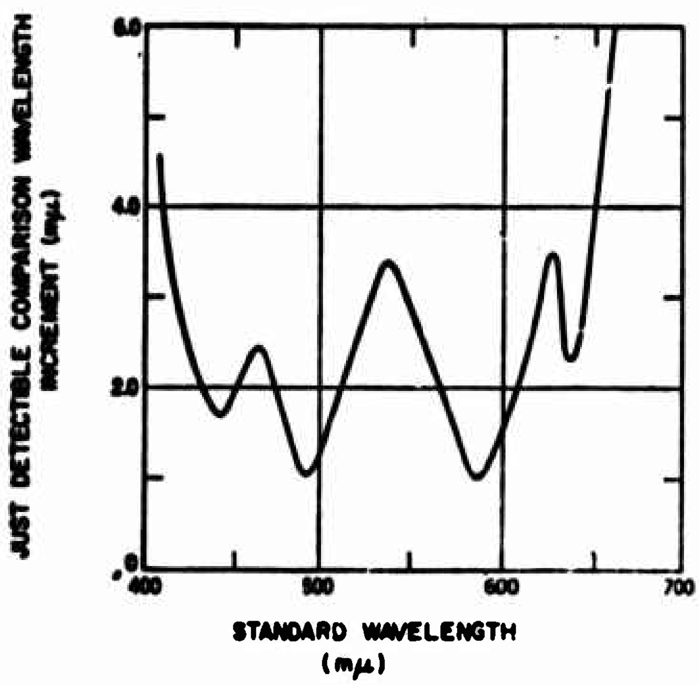

Figure 5-2. Increment of comparison stimulus wavelength required to produce a just detectible hue difference (Data from Jones, 1917; in Geldard, 1953, p. 42).

Yellow was found to be less discriminable than was orange-red of the same brightness against blue-gray backgrounds, simulating sea background colors, in open field tests (Malone, Sexton, and Farnsworth, 1951).

Wulfeck, Weisz, and Raben (1958, pp. 240-241) conclude that a red or orange-red target is most discriminable from the air against sea backgrounds and that an orange-red is best against terrain backgrounds. They note that there are few hue or saturation target-to-background contrast experiments for terrain backgrounds, either because sea contrast problems are more important in military aircraft contexts or because terrain backgrounds are more variable and, thus, less amenable to research.

Identification of Hues

There is a fairly general tendency to identify certain wavelengths with simple names. For photopic vision, the high wavelength extreme of the visible spectrum is seen as red; a wavelength of about 610 mμ, as orange; about 580 mμ, as yellow; about 510 mμ, as green; about 470 mμ, as blue; and about 420 mμ, as violet. For intermediate wavelengths, there is little agreement.

The effects of distance upon hue identification favor red and, next, white over other colors against black or blue-green backgrounds (Farnsworth and Reed, 1944).

Detection of Just Noticeably Different Saturations

Priest and Brickwedde (1926; 1938) determined successive steps of the minimum detectible colorimetric purity for different dominant wavelengths. Similarly, Jones and Lowry (1926) "stepped off" just noticeable differences of saturation for eight hue lines, intersecting at gray of the same brightness. The number of saturation j. n. d. 's for a hue was least --16 steps--for 575 mμ (yellow) and greatest--23 steps--for 680 mμ (red) and 440 mμ (violet). The two methods produced results in good agreement.

Color Blindness

Hsia and Graham (1965) have reviewed the literature on color blindness and the various tests for defining color deficiencies in relationship to normal color response.

For certain military tasks, normal color vision is certainly required. Examples are reading colored maps, differentiating ground targets from their earth backgrounds at close range, and identifying colored signals.

The need for normal color vision in detecting camouflaged targets is open to question. For targets at any distance, color may be an irrelevant factor, as was discussed above. In a relevant study (Wallace et al., 1943), subjects with normal color vision were consistently but only slightly more often correct in identifying roughly 9 x 9 foot irregular panels, painted with the usual camouflage colors, seen against different terrain backgrounds, from altitudes of from 1000 to 4000 feet. However, in a comparable study (reported in Hexter, 1944) color blindness was found not to influence the detectibility of 6 x 6 foot panels, painted with standard Army camouflage colors, on a grass background, seen from 1000 feet of altitude, when the panels were painted so as to present hue and saturation contrasts but negligible brightness contrasts with the background.

CHAPTER VI

REVIEW OF LITERATURE APPLICABLE TO PREDICTING THE SPATIAL DIMENSION OF VISUAL RANGE

Boring (1933, p. 28) points out that the dimension of extensity is obvious as a dimension of vision, since the retina is a spatial organ. The following comment is especially pertinent to the problem of this review:

> Perhaps the extensional nature of vision is emphasized by the fact that the entire visual field is always excited in visual perception. Even black is a 'sensation,' so that no visual sensory datum ever arises except as a spatial differentiation from the rest of the field. (Boring, 1933, p. 79)

In Boring's discussion of extensity (1933, pp. 62, 94-108) and in later discussions, extensity is considered primary, whereas size, form, distance, position, and localization are considered to be more complex organizations based on the dimension of extensity. Specifically, size and distance are codeterminate. Localization is somewhat more highly integrated than form. Form seems more immediate, since its references are internal. Localization requires external references for its definition, the frame of reference being usually visual, but not necessarily so. Thus, sensed spatial characteristics of targets and their backgrounds are discussed in this survey under the headings of size, distance, form, and localization and orientation judgments.

Of course, the psychological spatial dimension and the psychological temporal dimension are codeterminate in judgments of movement--displacement, velocity, and acceleration. These topics are taken up in Chapter VII.

Size Judgments

When judgments are made of the size of an object and the measures are corrected for distance from the observer's eye, then the size of the object is expressed as the visual angle (usually in minutes of arc) that a critical dimension of the object subtends at the optical nodal point of the observer's eye.

The size of the target is a major target characteristic in determining at what range the target can be seen (Hexter, 1944, p. 2). Hexter (1944, p. 8) contends that this aspect of the situation is not controllable in producing camouflage effects. It must be, however, measured to predict the results of camouflage schemes.

Detection of Just Noticeable Visual Angles--Visual Acuity

When the visual angle is that which the observer judges as just detectible, the reciprocal of the threshold visual angle is taken as a measure of the observer's visual acuity. Riggs (1965b) discusses visual acuity experiments. The critical object detail may be a dimension of the object, a separation between two objects or between each of a regular series of objects, or a change in contour. Many types of objects have been used in visual acuity studies. For a hairline, the visual angle may be 0.5 seconds of arc. For the separation between two black lines on an illuminated background, the visual acuity is about one minute of arc (Hexter, 1944, p. 2). For the Snellen Chart, used for medical examinations, 20/20 vision or normal visual acuity is defined as an acuity of one minute of arc; 20/40, 0.5 minute. This last notation raises an important point, made by Hexter (1944, p. 24) on the basis of field tests. To test camouflage schemes or to assign aircraft spotters in combat, individuals should be selected for normal visual acuity.

The data obtained by Blackwell (1946), reported by Duntley (1948a, 1948b), and discussed in Chapter IV, Figure 4-1, compared the effects of the background luminance and target visual angle upon the target-to-background luminance contrast required for detection. Thus, a target may be made just detectible against a background either by increasing its luminance contrast with the background or by increasing its size. In general, a small increase in target size compensates for a large decrease in contrast. This compensatory effect was more pronounced for complex forms as studied by Boynton and Bush than for the simple forms studied by Blackwell.

Middleton (1952, p. 90) has replotted the data of Figure 4-1 to show the target visual angle required for detection as a function of target-to-background luminance contrast for different background luminances. These interpolations are given in Figure 6-1.

The curves of Figure 6-1 are similar to data obtained by Cobb and Moss (1928), Connor and Ganoung (1935), and by Moon and Spencer (1944) for narrower variable ranges, using as an object a Landolt Ring. Again, similar results were obtained by Berry, Riggs, and Duncan (1950) for

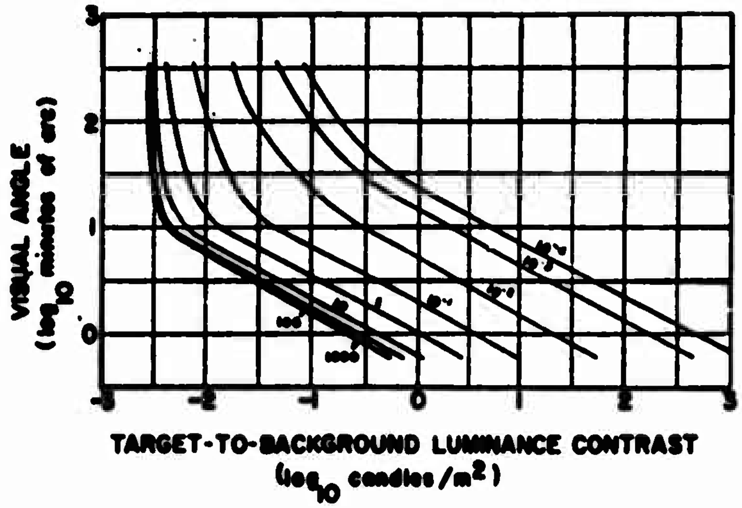

Figure 6-1. Visual angle for a target that is just detectible as a function of target-to-background luminance contrast for different background luminances (given in $\log_{10}$ candles/m^2) (Interpolations from Figure 4-1; by Middleton, 1952, p. 90; from the data of Blackwell, 1946).

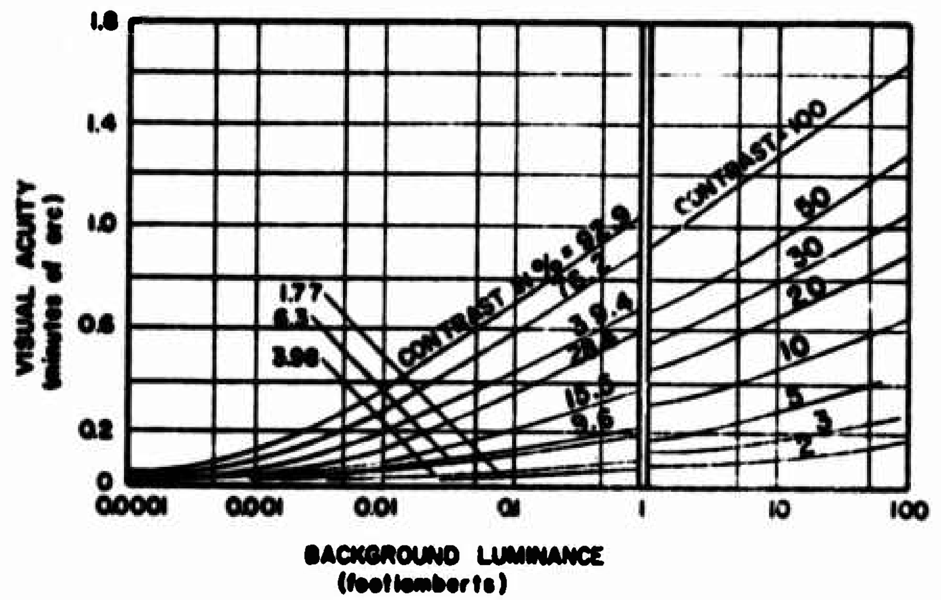

Figure 6-2. Visual acuity as a function of background luminance for different target-to-background luminance contrasts (Data on left, from Connor & Ganoung, 1935; that on the right, from Cobb & Moss, 1928; given in Chapanis, 1949, p. 31).

vernier acuity--the just detectible displacement between two line segments that would be continuous with displacement, the displacement being expressed as visual acuity. The data of Cobb and Moss (1928) and Connor and Ganoung (1935) are given in Figure 6-2.

For bright objects on a dark background, visual acuity may first increase and then, at about 10 mL, decrease with background illumination (Wilcox, 1932). This result occurs when there is a glare effect, that is, when the eye is not adapted to the level of illumination of the object or when the white object blurs due to irradiation.

A similar effect occurs when the general surrounding background luminance is different from the luminance of the immediate background against which the target is viewed (Lythgoe, 1932). For example, the immediate background may be an aircraft surface, the target may be two parallel bars placed on the aircraft surface and to be seen as separated, and the general surround may be the sky background of the aircraft. The data of Lythgoe (1932) are presented in Figure 6-3 to illustrate this effect, which is considerably important to camouflage. In general, visual acuity is best when the immediate and general surround are approximately equal. Less bright general surrounds produce slightly different effects in different experiments, but results in the luminance region of the immediate background are reasonably general.

Cobb and Moss (1928) obtained visual acuity measures for two dark bars separated by a light space of width equal to that of each bar for different background luminances, from 1 to 100 mL, for different contrasts from 1 to 100 per cent, and for exposure times of 0.075 and 0.300 seconds. Background luminance was the least important of the three variables.

The effect of hue on visual acuity has been studied from different points of view. In terms of its optical properties, there is reason to believe that relatively monochromatic blue light would give better visual acuity than would white or other monochromatic lights. This expectation has not been sustained in experimental comparisons (Shlaer, Smith, and Chase, 1942; Baker, 1949).

Of more general interest, the effect of hue upon visual acuity has been compared to the effect of brightness. The basic reference in this field was published by Eastman Kodak Company (1944) and is treated as a companion study to that of Blackwell (1946).

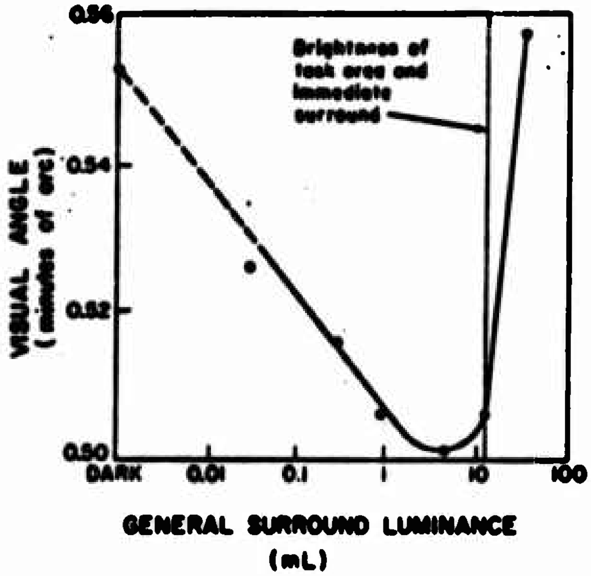

Figure 6-3. Visual angle of a just detectible target as a function of the luminance of the general surround (Data from Lythgoe, 1932; in Morgan, Cook, Chapanis, and Lund, 1963, p. 62).

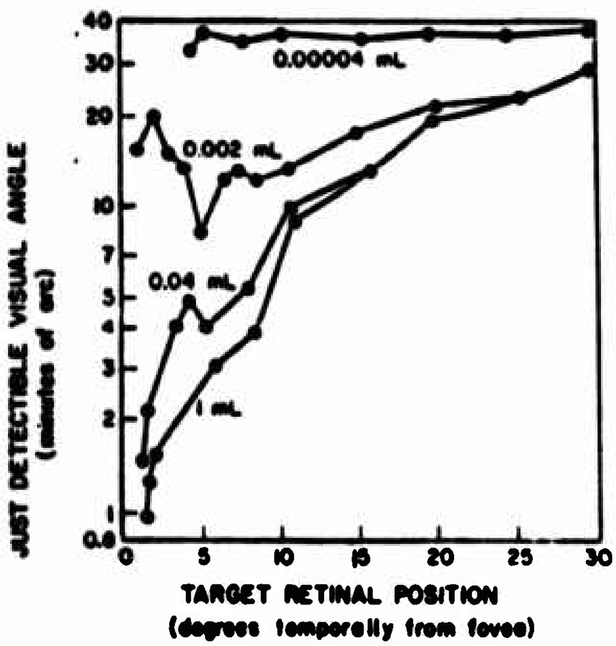

Figure 6-4. Visual angle required to detect a target as a function of retinal position of the target, for different background luminances (Data from Mandelbaum & Sloan, 1947; given in Morgan, Cook, Chapanis, & Lund, 1963, p. 65).

At high target-to-background luminance contrast levels, the addition of wavelength differences between the target and the background--referred to as color contrast--does not improve visual acuity markedly. However, at low target-to-background luminance contrasts, the addition to this brightness contrast of color contrast improves visual acuity appreciably. In practice, wavelength limitations of a target must be made at the cost of loss in source intensity or in transmitted or reflected luminance; in this case, emphasis upon luminance contrast is preferred. These results are given in the publication, as follows:

> ...the visibility of objects and acuity for identification of detail are primarily dependent upon luminance contrast under most field conditions. When luminance contrast is limited..., color differences may increase acuity and visibility, if chromaticity contrast can be introduced with equivalent sacrifice of luminance contrast. (p. 2)

It should be noted that the results were obtained as the visual acuity to detect the gap in a Landolt Ring, but that the authors apply these results to the visibility of targets and to other types of object according to the following reasoning:

> (a) For moderate achromatic and chromatic contrasts acuity* appears to depend on contrast in the same manner as visibility. Therefore, data obtained with test objects convenient for experimentation (such as the Landolt ring, employed in most of the present investigation) may be applied to other shapes by the determination of empirical conversion factors, using for these tests any convenient but definitely specified contrasts of object against background. If these conversion factors are determined by field tests, their application renders the laboratory data useful under those field conditions...

---

* For the purposes of this report, acuity will refer to the perception of critical detail such as is involved in the identification of distant objects. Visibility will refer to the bare detection of an object without identification. (p. 1)

(b) For high, increasing chromatic contrasts, acuity appears to increase less rapidly than visibility. This is believed to be a consequence of chromatic aberration in the eye but is not likely to be of importance in long distance observations since even the colors of highly chromatic signal flags are considerably desaturated by atmospheric haze. The magnitude of this desaturation can be computed for any specified set of conditions. The resultant acuity will depend on the decreased contrast, but the contribution of the decreased chromatic contrast can usually be estimated from the attached diagrams because the chromatic contrast is less than the limiting value above which the chromatic aberration of the eye becomes important. (p. 1)

By this means, the data of the report by Eastman Kodak Company (1944) can be treated as supplementary to the data of the report by Blackwell (1946). Also, this argument suggests the means of applying specific laboratory data to the field and of comparing different experimental reports.

Visual acuity is better in the fovea and decreases rapidly and progressively with placement of the retinal projection of the object farther into the periphery. This effect of retinal position upon visual acuity is important in estimating the probability that search over a given area will find an object of a certain size over a certain range (cf., Chapter VIII).

Wertheim (1894) studied visual acuity under daylight illumination for different retinal locations out to 70° nasally and 55° temporally. Placing visual acuity at the fovea as 1.0, relative visual acuity drops very rapidly, at first, and, then, more slowly. A minimum value of about 0.025 is reached at the nasal extreme and at about 50° temporally. Comparable data, at 1 mL and at lower background brightnesses, and for temporal retinal positions only, are given in Figure 6-4 (Mandelbaum and Sloan, 1947). These data show the better acuity at slightly parafoveal locations for low illumination levels that is the basis for the instruction to search for targets with parafoveal vision--at about 4° temporally--at night. The location of the blind spot from about 12° to about 17° nasally makes temporal search preferable to nasal search.

The part played by relative motion of the target and the observer in determining the target size required to make the target detectible is important in vision of an aircraft or in vision from an aircraft. The relationship between visual acuity and target angular velocity has been studied by Ludvigh (1948, 1949, 1953, 1955), Ludvigh and Miller (1953, 1955), and Miller (1958). For example (Ludvigh and Miller, 1953), for a Landolt Ring target, moving horizontally, visible for 0.4 second, under 25 foot-candles of illumination, visual acuity reduced rapidly with increasing angular velocity, approaching zero at 200 degrees of arc per second, and the rate of reduction increased with increasing angular velocity. However, in field tests (Dykes and McEachern, 1955), where the background is not uniform, visual acuity may be better for moving targets than for stationary targets. Motion may increase attention, even if it decreases visual acuity. Of course, in a real situation, an increase in relative speed is likely to be associated with a decrease in exposure time, thus reducing the likelihood that the target will be detected.

Estimation of Size

For suprathreshold objects, perceived size varies inversely with distance. If the visual angle of the object was the sole determinant of its judged size, the object would appear smaller proportionally as distance increased. If the size of the object was "corrected" for distance and seen as if at a constant distance, a constancy effect would be produced. The obtained results lie between these two extremes. As the environmental clues are varied, from unimpeded binocular vision, to the use of one eye, to the addition of an artificial pupil, and to the further addition of a reduction tunnel, there is a shift from an overcompensation for distance to dependence largely upon the visual angle of the object in judging size.

These data (Holway and Boring, 1941; Boring, 1946) are important in illustrating the possible differences in results that may occur between laboratory experiments with restricted visual observation conditions to the operational situations with unrestricted visual observation (cf., Thouless, 1931; Brunswik, 1944).

Form Judgments

The visual stimulus and observer characteristics that determine the perception of a form as distinct from its background have been studied in the context of gestalt psychology (cf., Ellis, 1938). For this reason, these data are not readily treated with data studied in other contexts. However, the

problem of form detection, identification, and estimation is highly important to military applications, especially to camouflage applications.

In general, these studies have found that a part of the total visual field is seen as an object with a defining form--and the remainder of the field is seen as background--if it is small with respect to the reference background, if it is relatively isolated in a simple background, if its outlines are relatively complete, if its brightness is different from the reference background, if its hue is one of certain hues that seem to stand out more readily, for example, red, and if it can be observed for a sufficient time.

Characteristics of the observer affect the judgment of form, for example, attitude and experience. Dykes and McEachern (1955) found considerable differences among experienced individual observers in a ten-day test of their aerial reconnaissance performance. They conclude that better selection and training are required for this task.

The interrelationships between the complex stimulus variables that define real objects and the observer characteristics of attitude and experience that affect their perception as forms with unique shapes or patterns are so complex that it is difficult to systematize this field. "... the practical goal is to isolate the characteristics of forms that make them easy to recognize" (Wulfeck, Weisz, and Raben, p. 123).

Identification of Forms

The identification of a form as compared to the detection of its presence was studied by Rose (1945). He varied target-to-background luminance contrast, target size, target distance, and atmospheric conditions. Two sizes of white, gray, and black panels were laid out on the ground to form symbols of the types: "TX"; "L"; "H"; inverted "U"; etc. These were observed from one of three different altitudes, with tests conducted for times when the visibility was good or when it was 3 to 6 miles. The observers were informed of the target position. A different target was in place on each run. The visual range for first seeing the panel was greater than that for identifying its pattern; for the longest ranges under favorable conditions the difference was about a 3 to 2 ratio and for unfavorable conditions the difference decreased.

Target identification by means of its form is affected by resolution (Baker et al., 1960; Williams et al., 1960). As a related factor, overlap with other objects will reduce form identification and separation between the target and other objects will increase form identification. However, Boynton and Bush (1955) did not find, as might be expected, that the probability of picking out the correct target was reduced by the density or the clustering of the heterogeneous objects in the display. Moreover, as expected, Boynton et al. (1958) and Baker et al. did find that search time increased with the number of irrelevant objects in the display.

The related problem of the subjective diffusion of the edge of a large object when it is only slightly above threshold target-to-background contrast may be important to the recognition of targets under a rather limited spread of viewing conditions, for example, in a fog (Middleton, 1952, p. 93). This phenomenon has been studied by Langstroth, Johns, Wolfson, and Batho (1947). It appears to be subjective rather than optical in origin. It is relevant to perceived form or shape, since it affects sharp contours chiefly.

Distance Judgments

Distance judgments may be aided by kinesthetic cues. These cues of accommodation and convergence are, however, weak as bases for distance judgments. Accommodation is useful only up to a few feet. Convergence is often corrected for.

The predominant cue to distance judgments in unrestricted vision is stereopsis, the disparity of the two retinal images. This is effective up to 1500 feet or more. Generally, because of the action of this cue, binocular distance judgments are better than monocular judgments, although beyond about 2,500 feet, monocular and binocular judgments are not different (Hirsch and Weymouth, 1947).

Cues to distance that require only one eye are: (1) the apparent size of familiar objects; (2) linear perspective, which is related to the first cue; (3) interposition of objects, at least for familiar or simple objects; (4) aerial perspective, the decrease with distance in outdoor viewing in the distinctness of detail, in saturation, and in target-to-background contrast; (5) light and shadow distribution, if the illumination is of known spatial distribution; and (6) movement parallax, the apparent different relative motion of objects seen at different distance.

Experience as a cue to distance is illustrated by Wulfeck, Weisz, and Raben (1958), in the following example:

> Association is illustrated by the following example. Five miles out on a low altitude approach to an air base, a pilot sees another aircraft nearly directly ahead. He does not know the type of aircraft; therefore he does not know the size, and the subtended angle cannot indicate the distance. But he notices that the aircraft is making turns as it would for the traffic pattern. Therefore, he is able to associate the distance with that to the airport. This cue, on the occasions when it is present, may operate at any range and may, in fact, interact with all of the preceding cues except, possibly, binocular disparity. (p. 122)

Detection of Just Noticeably Different Distances

Most distance judgment experiments are set up to emphasize the cue of retinal disparity and to determine the just noticeably distance difference between two objects. Such experiments use stereoscopic acuity as a measure. Stereoscopic acuity as low as 2 seconds of arc is obtained.

Stereoscopic acuity increases with background luminance as an approximate negative growth curve, with the asymptote beginning at about 10 mL (Berry, Riggs, & Duncan, 1950).

Estimation of Distance

Absolute distance judgments are very poor, although such judgments improve with experience.

Localization and Orientation Judgments

The problem area of space perception concerns not only visual distance judgments, but also judgments localizing objects in three dimensions or orienting oneself to three-dimensional space, in which the visual, kinesthetic, and vestibular senses combine to produce the judgment. These judgments require a frame of reference, for example, for the vertical and horizontal.

The problem of "empty field myopia" is an extreme example of the effects of having no visual reference. It is, also, an important limitation upon the visual range at which aircraft targets may be viewed from other aircraft. At high altitudes, there is a tendency to accommodate the eye to about 0.2 to 0.9 diopters, a level of near sightedness or myopia or a level appropriate to fixation upon near objects. There may be an associated convergence error. Koomen (1954), in the laboratory found that empty field myopia may reduce visual range by a half as compared to accommodation at infinity. Whiteside (1954, 1962) has discussed various devices to correct this situation.

The problem of "whiteout" may be similar. For ground or air personnel, spatial judgments are dangerously inaccurate when the environment, objects and details within it, and even the horizon are made uniform under certain atmospheric and illumination conditions. The problem requires further study, since no satisfactory solution has been found, as yet.

The illusions of orientation and motion occur, similarly, when outside visual or other important references are absent (cf., Wulfeck, Weisz, and Raben, 1958, pp. 195-196).

CHAPTER VII

REVIEW OF LITERATURE APPLICABLE TO PREDICTING THE TEMPORAL AND MOVEMENT DIMENSIONS

As independent physical, stimulus, or operational variables, time and movement are obviously important in affecting visual range. However, it is not clear to what extent the dependent variable of response in its temporal or movement dimensions is relevant to evaluating aircraft surface schemes. Certainly, the perceived temporal and movement characteristics of an aircraft target are important in identifying the target and estimating speed. Possibly, acceleration judgment is important in aircraft collision avoidance, interception, and the like (cf., Graham, 1965d). On the other hand, certain time judgments, such as judgments of the critical fusion frequency of flashing lights are not relevant to situations involving visual stimuli presented as continuous object surfaces, although these judgments would be highly relevant to the problem area of the conspicuity of an aircraft exterior lighting system (cf., Brown, 1965b).

However, treatment of the temporal and other time related aspects of the observer's perception of the target must be as summaries of a few experiments since so little applicable experimentation is available. In 1963, Boring made the following reevaluation of a chapter on the protensity dimension which he first published in 1933:

> The chapter on protensity... still seems to me important and sound.... Doubtless the chapter seems to me to have stayed alive because so little new work has been done in this field. (p. viii)

Middleton (1952) has recommended that more work is needed in this area, especially in relating perceived motion to predicting a target's visual range in outdoor viewing situations.

Boring explains the lack of interest in the temporal dimension by the difficulty of defining observations that are not momentary (cf., Woodrow, 1951, pp. 1234-1235). In all areas of science, the temporal dimension seems like "action at a distance," perhaps in producing uncorrectable biases (cf., discussion of the "time error" in Woodworth and Schlosberg, 1954, p. 225f).

There is, however, no difficulty in defining the temporal dimension or the related movement dimension. Any sensory datum varies in duration, just as it varies in extension, hue, saturation, and brightness. The former two, like the latter three, have a special affinity.

> The modern view assumes that protensity is coordinate with extensity, and that the problems that arise in respect of the one dimension are apt to be matched by problems for the other, except for the fact that extensity may actually involve within itself the three dimensions of space, whereas protensity is truly unidimensional. (Boring, 1933, p. 127)

However, although the temporal dimension may be unidimensional, the nature of the dimension may change as perceived time increases.

> Very short times are apt to be "immediately given in experience," to be "directly perceived." .... Longer times, up to five seconds or even more, may be of this kind; but the longer the time the more likely it is to fall out of the class of 'immediately' perceived protensions and to become the object of a judgment based on some secondary cue or a frame of reference. (Boring, 1933, p. 133)

An analogous break--or perhaps the same break--seems to occur in the psychological dimension of perceived movement:

> An aircraft a long way off has such a low angular velocity with respect to our eyes that we have no direct perception of motion. We know that it is moving only because its position or apparent size changes over an interval of time. As the aircraft comes closer, however, this more or less intellectual appreciation of movement changes to a direct sensation of motion. Thus, there are two stages to our perception of real movement: the <u>indirect</u>, for slow or distance objects, arising second-hand from our perception of a series of changes in size or position; and the <u>direct</u>, which occurs when these changes in position merge into a single sensation of motion. (Wulfeck, Weisz, & Raben, 1958, p. 124)

For both temporal and movement discrimination, the essential change in the nature of the perceived dimension may be a shift in the type of reference:

> The perception of movement is caused by (1) the successive location of the image at different receptors of the retina (i. e., movement in relation to the periphery of the visual field) and (2) the change in the location of the object with respect to other objects in the field of vision. Perception of movement is aided by movement of eye muscles and head to keep a moving object in focus, but these movements are not essential to the perception. When the object is moving rapidly, the successive images on the retina or in relation to fixed objects are synthesized in the brain into a single, direct perception of movement. (Wulfeck, Weisz, & Raben, 1958, p. 124).

Time Judgments

Woodrow has discussed time perception experimentation and concludes that much of the available information is conflicting or highly mentalistic (1951, p. 1224). However, he reviews data for two types of time judgment: (1) judgments of so-called "empty intervals," formed as the time interval between two light flashes; and (2) for "filled intervals," formed by a light which is continuous for a time period.

The manner in which the physical reference and comparison durations or the reference and reproduced durations are perceived by the observer varies considerably for different observers and can be modified by instructions (Woodrow, 1951, pp. 1227-1228). The two durations may be seen as a pattern, having a psychological aspect of rhythm, rather than of duration (cf., Benussi, 1913). Another group of observers, whether or not so instructed, seem to treat each comparison as a reproduction; when the reference duration is complete, they begin to reproduce the reference and seem to compare this reproduction to the comparison duration (cf., Kastenholz, 1922). Observers may differ as to whether they center attention on the physical stimulus or the experience (cf., Hulser, 1924, p. 367). In judging single durations, even more variety in the aspect of the duration emphasized by the observer is obtained (Woodrow, 1951, pp. 1229-1232). These differences in the observer's report of what he perceives when exposed to a duration and asked to make a judgment concerning its apparent time are important in application as possible different subdimensions of the temporal dimension of the visual response.

Detection of Just Noticeable Durations

The least physical duration that is perceived as having the quality of duration is considered to be one that is not merely momentary or instantaneous. Durup and Fessard (1930), using continuous light stimuli, obtained duration absolute thresholds of about 0.12 second. This judgment has, also, an upper limit; over about 6 seconds, continuous lights are not perceived as being in the present (Quasebarth, 1924). Both values vary considerably with the study and the conditions of the study (p. 1230).

Two visual durations that are physically separate are seen as single when they are separated by intervals shorter than from 0.200 to 0.025 second, depending upon the conditions of the physical stimulus (p. 1231). This value is the critical fusion frequency (cf., Brown, 1965b).

Detection of Just Noticeably Different Durations

Quasebarth (1924) found the just noticeable difference for discriminating the durations of 2 continuous lights to be about 7 to 14 per cent for reference light durations varying from 2.0 to 8.0 seconds.

Estimation of Durations

Summarizing results for both visual and auditory judgments, Woodrow (1951, p. 1225f) concluded that the scatter of reproductions of a duration increases with duration. As to the much-studied supposed tendency to overestimate short durations and to underestimate long durations first stated as a law by Vierordt (1868), Woodrow concluded that different studies have varied widely and even find contradictory tendencies; approximately, the indifference interval between the two tendencies is of the order of slightly less than a second.

Estimations of durations will vary with stimulus intensity, quality, and area, with the time between the reference and comparison durations, with time during the experiment, and with the range of durations presented (p. 1227).

The judgment of a "long" or a "short" duration depends in part upon the durations that have been presented and in part upon a tendency for such reports to be separated at the point of about 0.6 second (p. 1229).

Estimations of long times appear to be more a function of the type of experience that fill the time, the effect of physiological state, and the like, rather than a function of visual stimulus characteristics. Woodrow (pp. 1231-1232) reviews these factors.

Movement Judgments

Movement judgments may be made in one of two ways. The observer may be instructed to judge the velocity while displacement remains constant. Alternatively, he may be instructed to judge displacement while velocity remains constant. (Graham, 1965d, p. 575). The observer's sensation may be reported as a seen movement. However, J. F. Brown (1931a) has noted that as the physical velocity is increased, different perceptions may be reported. His stimulus was a pattern of black and white squares, viewed through an aperture which was relatively large with respect to the size of square, and with a central fixation point above the aperture:

> Brown found that, as the physical velocity of the moving square is increased continuously from zero to 200 cm/sec, the following thresholds are ascertainable: (1) just discriminable movement, (2) movement reported as a reversed movement, for example, when a square moves to the top of the field, disappears, and the succeeding square appears at the bottom of the field, (3) movement reported as equivalent to a movement of two or more squares, and (4) movement reported as equivalent to a continuous gray band (i. e., at "stimulus fusion"). (Graham, 1965d, p. 578)

Brown (1931b) studied, also, the effects of a moving figure made up of a sequence of black on white curves or squares and reached conclusions concerning the observers' perceived velocity. However, Smith and Sherlock (1957) concluded that the hypothesis was tenable that Brown's observers were responding, not in terms of apparent velocity, but in terms of the apparent frequency with which the curves or squares disappeared behind the edge of the aperture.

The threshold of movement which is reported to produce a continuous band, a fused stimulus, was studied earlier by Cermak and Koffka (1922), with a narrow lighted band, for different aperture widths and line luminances.

These different types of perception due to physical changes in movement illustrate the complexity of the field of the movement dimension in terms of the need for specifying all time and distance aspects of the physical dimension (Graham, 1965d, p. 579). They also emphasize the problems of knowing to what aspect of the stimulus the observer is reporting upon, of insuring that he is reporting upon the same movement aspect for different physical movement velocities or of determining the subdimensions of the movement dimension (cf., Graham, 1965d, p. 579-580).

Detection of Just Noticeable Displacements

It might be expected that absolute thresholds for perceived displacement would be of the same order as absolute thresholds for perceived size, that is, visual acuity thresholds. Basler (1906) obtained lower displacement thresholds; Stern (1894), Stratton (1902), and Gordon (1947) found similar displacement and acuity thresholds.

Basler (1906) found that the just noticeable displacement is lower for high than for low luminances, is lower as velocity increases, and is lower for foveal than for peripheral retinal position of the stimulus. Gordon(1947) shows gradual increase of the just noticeable displacement as the stimulus is located farther from the fovea.

In general, more systematic specification of rate and illuminance are required in this area, especially in comparing visual acuity and displacement thresholds (Graham, 1965d, pp. 577-578).

Detection of Just Noticeable Velocities

When moving objects, such as fine lines or a long line moving in a linear path (Aubert, 1886; Bourdon, 1902) or objects moving in a circular path (Grim, 1911), are viewed with fixation on the moving object and with the reference of the stationary parts of the apparatus visible, the least velocity that can be perceived is of the order of several minutes of arc per second. However, when visible references are screened, the minimum detectible velocity increases by a factor of ten.

For a "wallpaper" pattern of black and white squares, moving horizontally across the observer's field of view with a fixation point above the center of the stimulus area, Brown (1931a) found a just discriminable velocity comparable to that obtained by Aubert. The threshold is influenced by the length and width of the exposed field and the size of objects and distance between objects.

At short durations of exposure--about 1/4 second--the threshold is not influenced by the presence or absence of references; but at long exposure durations--about 16 seconds--threshold velocity is roughly halved by the presence of references (Leibowitz, 1955a). The author suggested that this change in the velocity dimension is due to a change from a situation where the discrimination is due mainly to initial sensory events to a situation where, at least, for slow speeds, the judgment is an observed change of position, i. e., an "inference" of movements.

The threshold velocity at a constant exposure duration is shown, in Figure 7-1, as a function of luminance--from 0.16 to 500 mL--for different exposure durations--1/8 to 16 seconds. Graham (1965d) summarizes these results, as follows:

> ...the threshold velocity at a constant duration of exposure (designated by Leibowitz as the isochronal threshold velocity) decreases with increasing luminance, rapidly at low luminances and more slowly before a limited value is approached at high luminances. The threshold-velocity luminance function shifts to lower velocity values as duration of exposure increases. (p. 576)

The effects of luminance and duration were also studied by Brown (1954, 1955) in terms of the least luminance required to detect the direction of displacement or velocity, for different velocities and for exposure durations of from 0.001 to 3.2 seconds. In his set up, it is not possible to know whether the subject was responding to displacement or velocity. Up to exposure durations of about 0.3 second, the conditions of luminance and exposure duration required for a threshold effect followed the Bunsen-Roscoe law ($Lt = C$); presumably up to this critical value, velocity or displacement is directly perceived or involves a single initial event dependent upon the product of luminance and duration. Above the critical value, $L =$ constant; luminance alone determines the least detectible displacement or velocity.

Bouman and van den Brink (1952) added to this formulation that, for moving point sources, not only a critical duration, but also a critical retinal distance is involved. They found that a movement is detectible when it exceeds a given stimulus energy absorbed by the retina, no matter how the energy is distributed in time or in space across the retina.

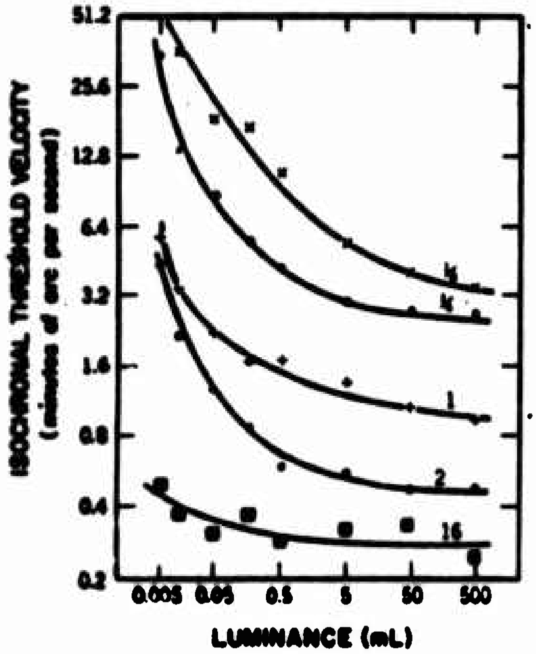

Figure 7-1. Minimum detectible velocity for a constant exposure durat'on (isochronal threshold velocity) as a function of luminance for different exposure durations (in seconds) (Data from Leibowitz, 1955b, as given by Graham, 1965d, p. 576).

The minimum velocity that can be detected is higher by as much as a factor of three for peripheral as compared to central retinal location of the stimulus (Aubert, 1886).

Detection of Just Noticeably Different Velocities

The change in velocity required to make a comparison velocity just noticeably faster or slower than a reference velocity can be expressed as

$$\frac{\pm \Delta V_o}{V_r}$$

When the comparison is produced by an instantaneous change in the reference velocity (for increments and decrements, Hick, 1950; and for increments only, Notterman and Page, 1957), the just noticeable ratio first decreases and then increases with the reference or initial velocity, with a minimum at about 1 to 2 degrees of visual angle per second or a ratio of the order of about 12 per cent.

When the reference and comparison velocities are viewed side by side, the least velocity difference that can be perceived is of the order of 1 to 2 minutes of arc per second for low reference velocities (Aubert, 1886) For a wider range of reference velocities, up to about 17 degrees of arc per second, Graham, Baker, Hecht, and Lloyd (1948) obtained lower just discriminable velocity differences for lower velocities of the reference than did Aubert. They also found that the just discriminable difference was only about 100 seconds of arc per second, even at the higher reference velocities tested.

Estimation of Velocity

When the judgment is absolute, that is, when no reference is available, velocity estimation is poor (Morgan, Cook, Chapanis, and Lund, 1963, p. 70).

Whether the reference could be viewed at will during the judging or was removed before the judgment was made did not affect the estimated velocity; but the scatter of judgments made after the reference velocity was removed became significantly higher (Smith, 1956). In this case, the reference velocity was above the threshold--24 ft/min, viewed from 12 feet.

In a study of longer exposure durations--six durations from 2 to 60 seconds--Goldstein (1956) found that longer observation durations resulted in lower estimates of perceived velocity, with most of the effect being in the middle range of the durations studied. In this experiment, observers fixated a spot above the center of the exposure aperture and made their estimates after the stimulus was removed by moving a hand stylus to reproduce the perceived velocity.

Acceleration Judgments

In military applications, judged acceleration of targets is an important problem. However, very little experimental data are available on this aspect of interrelated or combined time, size, and distance judgments (Graham, 1965d, p. 575). Morgan, Cook, Chapanis, and Lund (1963, p. 70) state that visual absolute estimation of acceleration is inaccurate and unreliable.

Acceleration has been studied in terms of vestibular responses and in terms of the response of ocular compensatory movements (cf., Stevens, 1951, pp. 1194-1197, 1199-1202). These responses are important to military aviation, but not to the subject matter of this report--the visual response.

CHAPTER VIII

REVIEW OF LITERATURE APPLICABLE TO PREDICTING THE "DIMENSION" TO WHICH THE OBSERVER WILL ATTEND

Few studies have been conducted in recent years in which the observer is asked to report on the clearness of the stimulus. Only such experiments are properly classifiable as pertaining to the sensory attribute of attensity (Titchener, 1919). However, several superficially quite different types of recent studies are alike in that they consider variables that are thought loosely to have a global effect upon the likelihood that the observer will attend to a stimulus. For convenience of description, these studies are brought together under an "attensity" dimension classification.

If these factors are best described as global and are not only apparently so because of the state of the literature, they may best be treated as correction factors applicable in the same manner to data such as that presented in the previous chapters. In the following pages, different examples are given of different treatments of these "global" factors. For search and scanning factors, a global treatment is illustrated. For optical materials and devices factors, an example is given of including this type of factor in the same way as other visual data may be included in a single equation predicting operational performance. For "stress" factors, examples are given of treating a specific type of stress as a parameter of an experiment on visual response, using a specific dimension and type of response and studying its relationship to other visual stimulus characteristics.

Search Requirements and Scanning Procedures

Characteristically, laboratory studies have studied visual detection, identification, estimation, and the like under conditions that are controlled so that it is not necessary for the observer to search for the target. This, as has been mentioned in the chapter on methodology, is a major difference between the laboratory and the operational situations. The requirement, in practical cases, includes requirements to scan a large visual field prior to detection, to locate a previously detected object prior to identification, and, in some cases, to relocate a detected object after break-off. Without doubt, adding this search requirement will affect at least the absolute values of the visual range required for detection, identification, and so on.

A flight experiment (Howell, 1957) conducted by the CAA in CAVU weather conditions (ceiling and visibility unlimited) illustrates the difference between the typical laboratory study, where the observer is fully prepared for detection of the target by providing him with a fixation mark at the same location and distance, and the field situation, where the observer may have varying degrees of prior information. In this study, observers are given one of three levels of prior information. The experimenter knew at what time, distance, and relative bearing an aircraft on a collision course with his own aircraft was to approach. In the informed observer group, each test pilot was told that he was on a collision course with another aircraft but did not know the relative bearing. In the misinformed observer group, each test pilot was informed that the experiment concerned the effect of two different instrument displays upon eye movements and was asked to report any aircraft sighted for safety purposes. Detection visual ranges for the fully informed experimenter were from 10-1/2 to 14 miles; for the informed group of pilots, from 4-1/2 to 5 miles; and for the misinformed group, from 3-1/2 to 5 miles.

This discrepancy between the visual range for detecting a target--in the laboratory situation where its location is known as compared to the field situation requiring search--is accounted for in several formulations of an estimate of the probability of detecting a target at a given range, given various operational search and scanning conditions. Bieber (1953) considers, chiefly, an estimate based on the relative speed at which two aircraft are closing. Lamar (1960) calculates the probability of detecting a target at a given visual range as the ratio of the region in space for which the eye is fixated, "the detection lobe," and the over-all area to be searched.

Any basic formulation of an estimate for the probability of visual detection must be correctible for the various factors which have been found in the literature to affect search time or search range. The parameters of the search and scanning procedures, itself, are important, including: flight speed, altitude, and duration; the search pattern flown by the aircraft; and the visual scanning patterns and rates used by the observers. In addition, certain factors may enhance or detract from these procedures; for example, the presence of useful references for controlling search patterns and speeds determines their optimum application. Time taken from search for other tasks, such as instrument reading, must be considered. The number of observers may affect the probability of detection at a given visual range; and the nature of this effect will depend upon the physiological fitness of the observers, their skill, and their training.

Characteristics of the visual stimulus, such as those considered in the previous four chapters, will, of course, affect the probability of completing a search at a given visual range. In this sense, search might be treated as a type of response, as was detection, identification, estimation, and the like. However, there is not yet sufficient data from carefully controlled experiments to warrant treating search in a manner analogous to these other types of visual response. For the present, at least, the state of the literature makes it preferable to treat search as a global factor.

Optical Materials and Devices

The observer's visual performance may be aided or handicapped by optical materials and/or devices added to the line of sight between the observer and the atmosphere, the target and background, and the illumination. These include magnifying devices, such as binoculars, telescopes, telebinoculars, and periscopes which are intended to assist him by increasing the visual range for detection or identification of targets or target details. These optical materials include, also, optical materials as a part of the working space--in aircraft, windshields and canopies--and personal equipment including optical materials, such as helmets, visors, and goggles.

Materials that act largely as filters, such as windshields, canopies, goggles, visors, and the like, will affect visual range for detection and identification according to their transmittance due to color and thickness; distortion due to slant, curvature, and optical quality; tendency to produce distracting or masking reflections; and tendency to accumulate surface deposits, such as dirt or fog or frost, or to be used under otherwise less than optimal optical conditions. (cf., Wulfeck, Weisz, and Raben, 1958, pp. 165-173).

The improvement in visual range due to the use of optical devices is not as great as that predicted from the magnification ratio of the optical device. This is due to a variety of additional, interrelated factors: contrast rendition and light transmission; increased effects of vibration and movement; limitations due to field size, pupil size, and eye relief; and limitations due to the design of optical system, its proper use, its optical quality, and its bulk and weight (cf., Morgan, Cook, Chapanis, and Lund, 1963, pp. 68-69, Wulfeck, Weisz, and Raben, 1958, pp. 173-179, 186-191). These authors give an illustration of the interrelationship among these factors:

> These might be conflicting factors, however, and any optical device has to be a compromise. For example, a large exit-pupil size makes the device much easier to use, but exit-pupil size is inversely proportional to magnification. And, again, increasing the diameter of the field permits increasing the exit-pupil size; but this means increasing the size of the optical parts, which leads to a bigger and heavier device. (p. 69)

Middleton (1952, pp. 95-96, 128, 130-132) has developed a general procedure, which checks with large scale tests at sea with different types of optical devices (Coleman and Verplanck, 1948), for correcting his general visual range equations for the contrast rendition and magnification of an optical device and, thus, predicting the visual range to be expected with the device. Analogous procedures could be developed for any optical device or material, given analysis of its characteristics, information as to which of its characteristics are relevant to visual range, and estimations as to which characteristics should be practically considered in view of expected prediction errors.

The transmittance of optical materials or systems can be entered into the formula predicting visual range by multiplying the term for background luminance by the transmittance; the significance of this correction may not be justifiable in terms of predicting the results of field tests, however (Middleton, 1952, p. 132). The effect upon the term for background luminance is not important in bright daylight, but may correspond to a significant improvement in visual range at night. Binocular devices may be preferable to monocular devices, especially under adverse conditions, such as at night; information in this area of knowledge is incomplete.

For search, per se, optical devices are not useful; for detection under adverse conditions, they may be useful, and for identification, they are clearly useful. The interaction of these situations--search, detection, and identification--is illustrated in the following:

> The performance of binoculars in search is different from their performance in identification, because of the scanning necessary in search. For binoculars to be of value in search, objects must be detected at a greater range than with direct vision. Even though the range at which objects can be seen with binoculars is greater than with direct vision, search for the objects presents a problem because the field of view

through the binocular is much smaller than the field of view with direct vision. Therefore, several times the number of fixations have to be made with the binoculars. In order to detect objects at a greater range with binoculars, search of the necessary area must be completed in less than the time required for the aircraft to travel the difference between the binocular range and the visual range, plus the time required to complete the direct visual search. For example, assume that the binocular range is six miles, the visual range is three miles, and the aircraft would travel one mile in the time required to complete a visual search. For the telescope search to be of more value than the visual search (based on 100 percent probability of detection), it must be accomplished in less time than is required for the aircraft to travel 6 - 3 + 1 = 4 miles. Since a large number of fixations are required to completely search a field through binoculars, the faster aircraft travel a considerable distance during this time, consuming most of the difference in visual range. . . . .

On the other hand, the value of binoculars is definite in identification, where the object has been found already by naked-eye search. Identification should always be faster through the binoculars, except where there is excessive time loss in finding the previously detected object in the binocular field. If there is a means of promptly locating the detected object in the binocular field, there is no appreciable field to scan, and so ordinarily a large amount of time is gained in identification through the binoculars. Therefore identification by binoculars has a definite range advantage over that by direct vision, provided some of the problems in binocular usage are solved. (Wulfeck, Weisz, and Raben, 1958, p. 187)

"Stress" Situations

The observer in military situations may be assumed to have met rules selected to bring him to an optimal state for his military tasks, including any visual tasks that may be required of him. In practice, it may be practical to estimate to what extent he has deviated from this standard procedure or to estimate to what extent the conditions under which he operates force deviation.

Standard procedures as to smoking, use of drugs, including alcohol, proper diet, and rest may not be met, especially in wartime. These variations may produce loss of sensitivity, loss of depth discrimination, restriction of the visual field, enlargement of the blind spot, difficulty in focusing or association, or even difficulty in keeping the eyes open (cf., Wulfeck, Weisz, and Raben, 1958, pp. 142-143).

In general, these "stress" conditions are equivalent to more readily definable stress conditions, such as altitude and acceleration. For example, McFarland, Roughton, Halperin, and Nevin (1944) found that three cigarettes are equivalent to more than seven thousand feet of altitude in their effect upon the absolute threshold of the fully dark adapted eye.

Altitude, as a factor affecting visual performance, is not important if it is assumed that the lowered oxygen supply to all tissues and to the visual system that would result from increased altitude is adequately corrected by the use of supplementary oxygen systems. If this supplementary system fails, however, visual sensitivity is considerably impaired, increasingly with higher altitudes and for greater durations of exposure. Correction for formation of blood nitrogen bubbles with rapid altitude ascents by means of pressurized cabins can also fail, resulting in hazy vision, visual field restriction, and scintillating blind spots (cf., Wulfeck, Weisz, and Raben, 1958, pp. 141-143).

Acceleration stress is not completely correctible in high performance aircraft by such devices as "G suits." Visual performance may deteriorate at as little as three g (cf., Wulfeck, Weisz, and Raben, 1958, p. 141).

These and similar factors are studied in considerable detail in McFarland (1953). Currently critical flight problems due to "stress" factors are discussed in the collection of papers presented by Mercier (1962). Individual stress conditions are defined and discussed by Morgan, Cook, Chapanis, and Lund (1963, pp. 411-484).

CHAPTER IX

FUNCTIONAL SYNTHESIS

This research program was described (Chapter I) as based on the need to provide a more full statement of the human engineering requirements of an aircraft surface camouflage system. This system is treated as a part of a higher order system including parallel systems designed for other purposes, such as conspicuity.

In a discussion of the methodology for predicting the operational performance of systems (Chapter II), it was concluded that a literature survey was the most practical means of obtaining information on the visual requirements of a camouflage subsystem. Further, it was concluded that this method was adequate in generality for this purpose. Its precision, of course, is limited by the precision of the studies reviewed. To improve generality and precision, emphasis should be placed upon relative rather than absolute values for stating the operational performance of alternate aircraft surface camouflage schemes.

An aircraft surface camouflage system was described in a functional analysis (Chapter III) as including the components of target, background, illumination, and atmosphere as independent variables and the component, visual range, as the dependent variable. Because the range is defined by a visual response, the problem studied in this research program is treated as a psychological problem. Thus, the characteristics of a visual response define the areas of the human engineering literature that may be relevant to predicting visual range.

Accordingly, the body of this report consists of a review of the literature from the point of view of the different dimensions of the visual response--the brightness dimension (Chapter IV), the hue and saturation dimensions (Chapter V), the spatial dimension (Chapter VI), the temporal and movement dimensions (Chapter VII), and the "dimension" of those variables that affect the observer's capacity to attend (Chapter VIII). For each dimension, data was sought for the different types and levels of visual response. The response types considered, here, included search, detection, identification, estimation, decision, and action. However, as was anticipated, the bulk of the available literature concerned the dimension of detection. The "search" problem was included in the chapter on the observer's state, since it has not been studied in terms of visual response dimensions, but rather has been treated globally as "visual" search.

These data are, now, considered as a whole in an attempted functional synthesis. Ideally, the data would be weighted according to their contribution to visual performance and, then, would be expressed in a single formulation predicting visual performance from the various conditions. Some of this data has been organized by means of equations predicting the visual range of targets under outdoor viewing conditions by Duntley (1946a, 1946b, 1948a, 1948b) and Middleton (1952).

Visual Range of Objects Seen along Horizontal Paths against the Horizon Sky and along Slant Paths against the Sky

The situation of viewing targets along horizontal paths against the horizon sky is treated as basic by Middleton (1952, pp. 104-108) because it can be developed on the basis of one simplifying assumption:

> ...the uniformity of both light and atmosphere, not just between the observer and the object, but between him and the horizon....The extinction coefficient is the same all along the path, and will be called $\underline{\sigma}_o$. (p. 104)

In this case, we have a clear description of the effect of the atmospheric extinction coefficient in changing the inherent target-to-background contrast (C_o)--the contrast as measured at the target--to the apparent target-to-background contrast (C_R)--the contrast as determined at the observer's eye. This distinction is basic to all of sensory psychological research. It is usually expressed as the transformation of the mediate stimulus to the immediate stimulus by intervening conditions, for example, optical devices or the optics of the eye. In the latter example, this distinction is the basis of transforming a stimulus measure of luminance to one of retinal illumination, according to the size of the observer's pupil. From this point of view, the optics of the atmosphere are in the same class as the optics of special viewing devices and the optics of the eye; all of these intervene between the stimulus and the retina. Therefore, this and other similar developments should be readily generalized to cover different types of viewing medium.

In the present development, the change from inherent to apparent contrast is a function of the extinction coefficient and the range. At a certain determinable range, the apparent contrast is such that the target is just noticeably discriminable as distinct from its background, where this range is determined by the criterion of visual response. The value of R at this range is called V: the visual range. The absolute value of C_o at V is called S. Therefore,

$$\underline{\epsilon} = C_o e^{-\underline{\sigma}_o V} [\,|C_o| > \underline{\epsilon}\,],$$

or taking logarithms and simplifying

$$V = C\,|\,/\underline{\sigma}_o)\log_e|\,C_o/\underline{\epsilon}\,].$$

Nomograms for Estimating the Visual Range of Objects Seen along Slant Paths against the Sky

It is difficult to calculate actual values by means of the equation presented above. This calculation is made difficult because of a psychological finding, mentioned in this literature survey, that $\underline{\epsilon}$, the threshold target-to-brightness luminance contrast, varies with the visual angle of the target, which, in turn, varies with visual range. Solution of the equation requires a series of successive approximations to meet this requirement.

As an alternative to calculating the actual visual range, nomograms were developed by Duntley (1948a). Middleton (1952, pp. 108-109, 119) describes their development and derives the following equation:

$$C_R = C_o(B_o'/B_R')e^{-\underline{\sigma}_o \overline{R}} \quad .$$

This is rewritten as

$$C_R = (B_o'/B_R')C_o e^{-3.912\,\overline{R}/V} \quad ,$$

where the exponent is given by

$$\underline{\sigma}_o = 3.912/V_2 \quad .$$

The basic nomograms presented by Middleton (1952, pp. 110-118) are applicable for estimating the visual range of an object viewed along slant paths against the sky, for the following sky background luminances:

1000	foot-lamberts		(full daylight)
100	"	"	(overcast day)
10	"	"	(very dark day)
1	"	"	(twilight)
10^{-1}	"	"	(deep twilight)
10^{-2}	"	"	(full moon)
10^{-3}	"	"	(quarter moon)
10^{-4}	"	"	(starlight)
10^{-5}	"	"	(overcast starlight)

The first of these is reproduced in Figure 9-1, as an example. Middleton (1952) describes the nomograms and their use, as follows:

> In these nomograms, which were obviously constructed for military use, ranges are given in yards, target areas in square feet. The value of background luminance to which each nomogram refers is an integral power of ten in "foot-lamberts," called "equivalent foot-candles" in the United Kingdom. One foot-lambert is the luminance of a perfectly diffusing surface of luminance factor $\beta = 1$ which is receiving an illuminance of one lumen per square foot. It is equal to 3.42 candles/m^2, or 10.76 apostilb.
>
> These nomograms are very simple to use. Referring to Figure 9-1, suppose it is required to find the extreme distance that an object 1000 sq. ft. in area could be seen* in full daylight on a day when V_2 is 9000 yards, if the inherent contrast of object and sky is 0.8. All that is required is to lay a straight-edge across the diagram, meeting the scale of meteorological range at 9000 yards and the scale of contrast at 0.8. The range required (6,600 yds.) is read off at the point where the straight-edge intersects the curve marked "1000 sq. ft." by projecting this point straight up or down to the scale marked "sighting range."

* With a probability of 95 per cent. (p. 108)

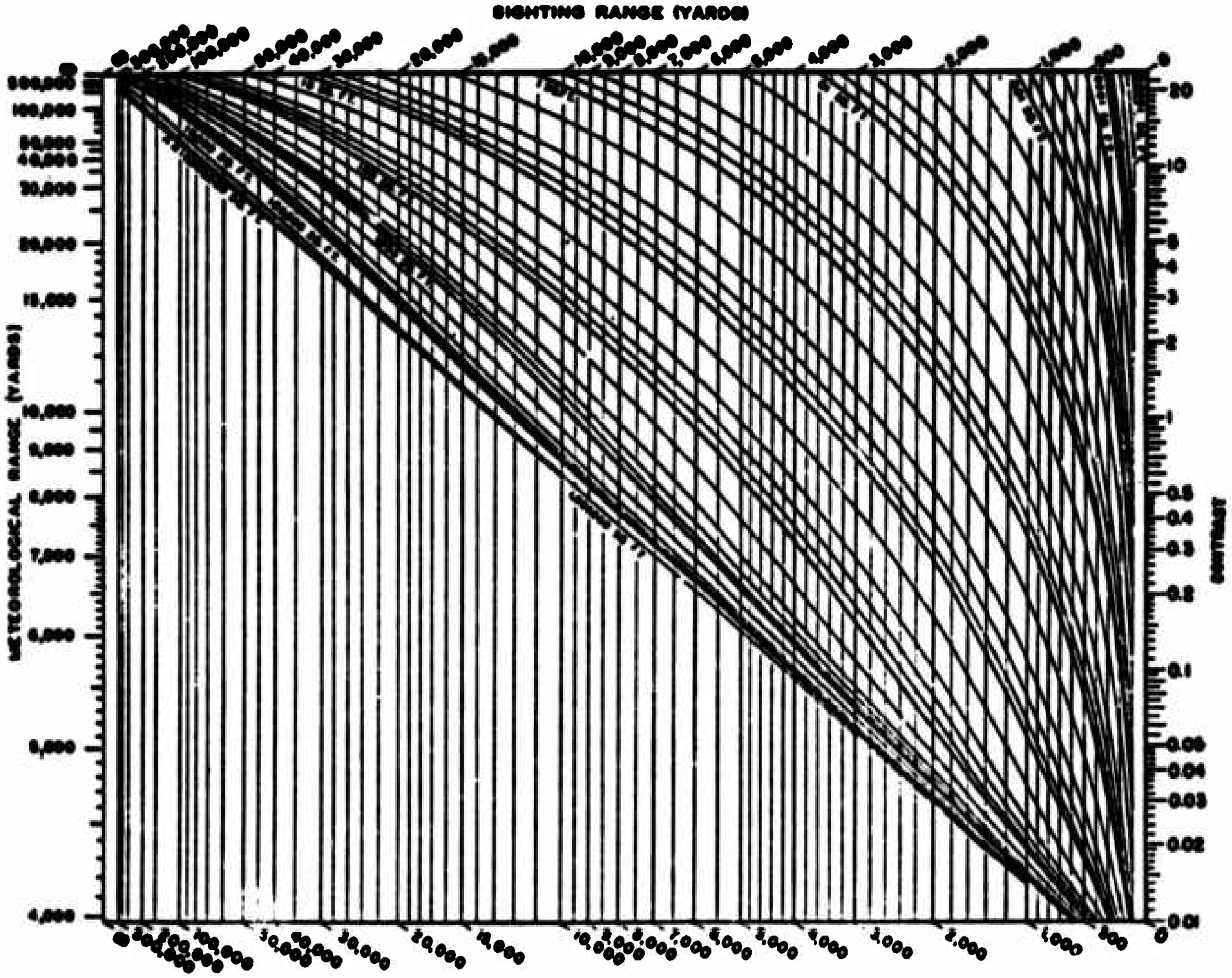

FIG. 6.3. Sighting range in yards of objects against the sky, background luminance 1000 foot-lamberts (full daylight), based on the Tiffany data for circular targets, at a probability of detection of 95 per cent.

Figure 9-1. An example of a nomogram for estimating visual range (Middleton, 1952, p. 110).

Distances beyond the range of the chart (in particular meteorological ranges lower than 4000 yards) may be dealt with if both the meteorological range scale and the sighting range scale are multiplied by the same factor, provided that the area assigned to each curved line is multiplied by the square of this factor.

If the straight-edge is placed so as to intersect the scale of meteorological range at its infinity point, the nomogram may be used to find the threshold contrast for any object of a given size at any assigned distance. In this way it acts as a plot of the Tiffany data for the particular background luminance for which it is constructed. It should be remembered that these nomograms refer to circular targets; nevertheless, they apply to targets of any not-very-extended shape with little correction. (pp. 109-119)

Visual Range for Other Viewing Conditions

The main emphasis in Middleton's work (1952) is upon extending this formulation of visual range to other conditions. With reasonable generality, he has extended the concept to the following problem areas:

(1) Objects seen along horizontal paths against terrestrial backgrounds (pp. 122-126)

(2) Objects seen looking downward (pp. 126-128), a nomogram is presented for this case (p. 129)

(3) Objects seen through telescopic systems (pp. 128, 130-132)

(4) Objects that are light sources and objects that are illuminated with artificial light (pp. 137-144)

(5) Objects that are colored (pp. 145-174)

(6) Objects viewed with a camera, that is, prediction of photographic range (pp. 134-136)

In one attempted extension of the concept of visual range and the related prediction equations, Middleton found the development difficult and, perhaps, impossible. This is the case for forest fire smokes (pp. 132-134). Middleton states that this type of formulation may not apply to any object, such as this, which is of indeterminant contrast and size.

Field Tests of This Formulation for Predicting Visual Range

The few sufficiently extensive field tests of this development have shown adequate agreement among laboratory, theoretical, and field considerations. The Roscommon tests (Blackwell, 1949) agreed within $\pm$ 25 per cent with the Tiffany data (Blackwell, 1946) as formulated by these equations (Middleton, 1952, p. 95). Good agreement has, also, been found by Coleman and Verplanck (1948) and others.

Therefore, it can be concluded that this method is a promising means of organizing the visual literature to predict the operational performance of targets, such as aircraft treated with special surface materials, when viewed under outdoor conditions.

However, the review of the literature has located certain persistent problem areas that require further data or further formal development before they are amenable to this type of formulation. Some of these problem areas are discussed, below. Most of them have been raised in the course of this report.

Basic Assumptions

Middleton (1952, p. 136) points out that of the basic assumptions involved in his formulation, three are only approximately fulfilled. Of these, the assumption regarding the curvature of the earth is negligible except for very long ranges of the order of tens of kilometers. However, the assumptions of the uniformity of the atmosphere in the horizontal and the uniformity of the illumination are obviously not fulfilled in the field (cf., Chapter III, pp. 28-30).

Measurement and Prediction

The problem of measuring and predicting the basic independent variables required for estimating the visual range of an object was discussed above (Chapter III, p. 30). The value of the variables of background luminance can be readily estimated. The value of the variable of target characteristics can be estimated or extremes can be set. However, the measure-

ment of atmospheric attenuation requires development (1952, pp. 175-225, 227-228). In terms of the applicability of this development, Middleton believes that this problem is at present the limiting problem:

> ... the final conclusion that may be drawn is that <u>if you want to know how far something can be seen, learn to measure the photometric properties of the atmosphere</u>. This is the real text of our sermon. (1952, p. 227)

A major obstacle to learning how to measure the atmospheric properties is the prevalence of the overlapping measure of meteorological visibility (Fitts, 1951, pp. 41-42; Middleton, 1952, pp. 227-228).

In application, it is more often of interest to know what will happen than to know what is the current situation. In applying exterior finish schemes to military aircraft, it is necessary to predict the variables mentioned, above. By this reasoning, a problem similar to and including the problem of meteorological prediction is raised. Time changes in the characteristics of the background, the illumination, and the atmosphere must be considered in selecting a target surface treatment according to such means as those illustrated in Figure 9-1.

Determination of the Actual Viewing Conditions

Both Fitts and Middleton see as a possible solution to the measurement problem, redefining the event to be measured so that it is of more immediate applicability. For example,

> Even if it were possible to obtain a satisfactory measurement of a physical correlate of meteorological visibility, the measurement would not predict how far objects of interest will be seen by the pilot. It is obvious that few objects of interest are indefinitely large and dark . (Fitts, 1951, p. 42)

The same idea is placed at a different level in the development of prediction equations by Middleton (1952):

> It is now his (the author's) considered belief that there is only one way in which meteorological observations of this element can be rescued from complete futility: abandon the entire scheme of marks and estimates, make good instrumental measurements of the extinction coefficient and then calculate something which will be of interest to the user of the datum. The writer's Sub-commission has been trying to arrive at a value of ε by which some sense could be made out of estimates of daytime "visibility." This is a wild-goose chase. What should be decided by some appropriate international body is a standard way, or set of ways, to present to the final consumer the information that can be derived from good instrumental measurements: for example, how far a certain kind of object can be seen against some agreed background - probably differing with the time of year. This would be a "visibility" with meaning.
>
> The above strictures, of course, apply *a fortiori* to estimates based on unspecified lights at night, always made by an observer whose eyes are in an unknown state of dark adaptation. In the nocturnal case it will probably be difficult to choose a state of adaptation for the hypothetical user. (p. 228)

Thus, Middleton introduces the need for representative surveys of what the actual viewing situation is - in his terms, "the study of the actual conditions under which those in charge of moving vehicles have to use their eyes, both by day and by night." (pp. 228-229). This problem has been raised in the course of this report in several contexts, especially in the discussion of methodology in Chapter II (pp. 5, 6-7, 14). It is especially pertinent, as the above quotation indicates to adaptation level and motion conditions. When such data are available, it would be possible to solve a related problem, that of conducting experiments under conditions that are more readily applicable to outdoor viewing conditions.

Specific Areas of Visual Response in which Further Research is Needed

An outstanding problem is the relative lack of experimental data on the more complex visual responses, such as identification, estimation, decision, and action.

Data are also needed concerning the dimension of movement and the effects of nonuniform targets and backgrounds.

Conclusions

For reasons discussed, above, some important problem areas have not been or, perhaps, cannot be brought into this formal prediction equation. It is suggested that, when such problem areas are known by other criteria to be relevant to a design problem, the available data may be taken, as it is, to estimate an informal correction factor, which, when applied to the formal prediction equations, will allow them to be used for the immediate design problem. It is for designs so derived that operational tests are needed before a design is accepted. Operational tests would, also verify or reject the correction factor estimate. Further, the tests would, in some cases, point out what steps must be taken to develop the prediction equation so that it formally covers the problem area.

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APPENDIX A

Preliminary Functional Analysis of Aircraft Surface Schemes, Emphasizing Control and Maintenance Functions and Engineering and Human Engineering Requirements for these Functions

The functional analysis of aircraft surface schemes, in Chapter III, and the corresponding functional synthesis, in Chapter IX, emphasize the visual human engineering requirements involved in predicting a scheme's operational performance, from the point of view of an observation function, from target and environment conditions, treated from the point of view of an operation function. This appendix supplements these analyses by presenting, on a preliminary level, a functional analysis of the engineering and human engineering requirements involved in the control and maintenance functions which, with observation and operation functions, describe an aircraft surface scheme, as it is used in the Fleet. The reasons for this separation of functions were given in Chapter I.

The roles of these four functions in describing or generating the Fleet situation can be illustrated as if four hypothetical persons were involved: a "controller" who decides what surface scheme to apply to the aircraft; a "maintainer" who applies, repairs, removes, and similarly maintains the surface treatment; an "operator" who pilots the certain type of aircraft with a special surface treatment through a complex environment on an assigned mission; and an "observer" who attempts to "see" the aircraft target so that he can decide what action to take concerning it.

Control Function

The essential component of the control function in the Fleet use of an aircraft surface system is the making of a decision to select one from a set of aircraft surface schemes. This selection is made by comparing all possible pairs of alternate schemes as to the relative effect of the two members of the pair upon the level of a certain type and dimension of the observer's visual response, when the aircraft is of a designated type and is flying a planned mission in a measured or predicted environment, describable as to the conditions of the illumination and the atmosphere (cf., Chapter III).

Control Decision Measures

Since the control decision is essentially an estimate of the potential observer's action, the validity of the control decision is ultimately so defined. This definition of validity could be used in flight tests. However, in the use of a scheme with hostile observers, a related measure of the validity of the control decision is taken--the success of the mission or of the part of the mission for which the special surface scheme was judged to be appropriate. Related part measures may be used to express the adequacy of the control decision, for example, the speed with which the decision was made or the precision of prediction of mission conditions.

In practice, user acceptance is sometimes the "defining measure." In this case, the user is the pilot. His opinion as to the usefulness of the scheme in accomplishing the mission may provide information as to the adequacy of the control decision. More important, however, is to determine, as a possible source of bias in other measures of the control decision, whether the pilot's accomplishment of the mission occurred because he followed the specifications for the use of the treated aircraft, because he deviated from these specifications to accomplish a successful mission, or because his mission was successful despite deterioration in the mission due to his deviation from specifications.

Visual Range

The control decision is, in part, determined and may be measured as to effect of the selected scheme upon the observer's visual search, detection, identification, estimation, or upon his decision, if one or more of these is considered to be essential in determining the observer's action. Any one of these responses of the observer can be expressed as a visual range--the distance between the observer and the aircraft when the response occurred. Or if an action is taken or if it is the significant observer response, the resulting range may be evaluated according to whether the pilot could or did take successful counteraction (cf., Chapter III, pp. 23-28).

Aircraft Type and Mission

The aircraft type and mission must be considered, although individual aircraft types and missions may be classed in relatively few groups to facilitate the decision. It is necessary to adapt generalized surface schemes for the particular aircraft type. The mission of the aircraft and its most recent and possible later missions are a factor in maintenance problems of removing one scheme and applying another, with associated problems, such as down time, finish damage, and so on. The intent of the mission or a critical part of the mission is of considerable importance in making the control decision.

Environment

The environment must be considered, as to which of alternative schemes is appropriate under prevailing and anticipated illumination and atmospheric conditions.

Control Decision Aids

The availability and appropriateness of control decision aids may affect the decision outcome. This support may be designed to promote acceptance of the system, to provide brief on-the-job demonstration or training in the system's use in the Fleet, to provide general background references, manuals, and the like to clarify the purposes of the system, and/or to measure and predict the relevant parameters of the environmental situation.

Standards as to Authority and Responsibility

Especially if they are set up clearly, prior to the decision, and are properly published, procedures can improve control decisions considerably. These standards may include the Fleet person or group responsible for the control decision, the scope of this Fleet responsibility, the person or group and the scope of the corresponding authority which assigns this responsibility, the methods to be followed in coordinating Fleet and central actions and for standard use, authorized deviations, and requests for waivers.

Number and Types of Alternatives

A control decision is made more adequate by reducing the number of alternatives or by organizing alternatives into types according to some criteria, such as their conditions of use. In the present case, organization might be accomplished by treating the aircraft camouflage surface schemes as a set within an aircraft camouflage surface subsystem. This may be treated as parallel to an aircraft conspicuity surface sybsystem and an aircraft surface subsystem for normal operations; these subsystems may be organized into a general aircraft surface system; and so on (cf., Chapter I).

Alternatives exist for camouflage, such as hiding or maneuvering (Brown, 1963). Taking evasive action is the normal alternative to an aircraft conspicuity system for collision avoidance; other alternatives or supplements include air traffic control systems, training in scanning and maintenance of pilot alertness, safety training, improved communications, etc. (Siegel & Federman, 1965). Other than visually defined measures may be alternatives to these aircraft surface treatment measures to obtain the same mission results (Wulfeck, Weisz, and Raben, 1958).

Maintenance Demands

The effort and cost required to remove or apply and to maintain an aircraft surface scheme will certainly be a major determinant of the control decision. Certain schemes may provide relatively little or relatively restricted mission advantage but may require considerable maintenance effort. Certain schemes may produce damage to the aircraft exterior or their removal to apply another scheme may damage the first scheme. The cost and availability of materials, the safety of methods, the availability and training of personnel, the appropriateness and availability of workspace and equipment must all be considered in scheduling a surface scheme change and its maintenanc and so will, in part, determine the scheme selected.

Maintenance Functions

Maintenance functions act as limitations upon the design, selection, and use of aircraft surface schemes. Field maintenance conditions must be considered, since aircraft exterior finishes are maintained in the Fleet (cf., NAVSHIPS 94324, Bureau of Ships, Design Criteria for Maintainability).

Selection of Methods and Materials

It was concluded, in preliminary planning, that only standard aircraft surface materials and methods are to be included in any proposed aircraft camouflage surface scheme in this research program. Therefore, it is not necessary to develop, test, prepare specifications for, or prepare instructions for new materials and methods (cf., Federal Standard 141). However, it is, of course, necessary to select particular materials and methods from those that are currently standard. This selection would be made by the same criteria that would apply if all possible materials and methods were being considered.

Standard materials include paints, including phosphorescent and fluorescent paints, fabrics, films, decalcomanias, tapes, placards, and metal surfaces with various chemical treatments and the like, and covers. Specifications describing these various surface treatments and their use are listed in the references to this appendix.

Effort, Cost, and Supply

These materials are, for some uses, alternate aircraft surface treatments. Selection for an aircraft surface scheme would be made, in part, by the criterion of the relative ease with which they are applied, inspected, maintained, repaired, and removed. Their relative cost would be considered. The relative ease with which they could be supplied, especially to remote theaters, may recommend one of these materials in lieu of another. Supply problems would be reduced if materials used for other purposes are used for proposed specialized-use aircraft surface schemes.

Damaging Agents

Materials should be preferred that are relatively less susceptible to damaging agents. Damaging agents of different types may be anticipated on certain aircraft locations, in certain environmental situations, etc. Thus, special materials for these special applications may be selected, with more routine materials being used elsewhere.

Damaging agents may be, for convenience, classified as material, abrasion, and radiation.

Materials that may be damaging include paint removers, spilled acids and alkalis, fuel leaks, synthetic lubricants or oils, exhaust trails and gases, or any other corrosive agent. Normally accumulating foreign materials must be included as a source of damage. Normal weathering can produce damage by way of naturally occurring agents, such as rain and salt spray.

Abrasive action damage may occur by improper sanding, cutting, or weighting during maintenance or improper weighting during operations. During operations, gun and rocket blast may cause damage. Weight or roughness of the surface may affect operations. Accelerated movements may produce damage, even at low speeds, but especially at supersonic speeds.

Radiation damage may occur even during maintenance due to improper application of special methods that are sensitive to temperature used. In operations, ambient heat radiation or the heat of exhaust trails and gases may be damaging, even at low temperatures. Special materials and methods are required for ambient temperatures of heat radiation above 300° F, or 350° to 500° F, for ultraviolet radiation and for thermonuclear radiation.

Aircraft Finish Integrity

Even a well maintained aircraft exterior finish is subject to damage due to weathering, if from no other source. A clear acrylic coating will provide protection from ultraviolet radiation and rain erosion. Such systems are described in Military Specification MIL-C-27315, Coating Systems, Elastomeric, Thermally Reflective and Rain Erosion Resistant.

Protection of the finish is especially important for aircraft exterior finish schemes selected to produce required routine identification or special conspicuity or camouflage effects. As finishes chalk, they change color from that selected to accomplish the specific purpose. This change may be included in the design of the scheme as, for example, in the following:

> It is extremely important once reflection factor requirements are determined to make certain that paints on weathering do not change their reflectivity. It seems reasonable to specify a paint which when freshly applied has a reflectivity of 6%, which is still excellent when the airplane is parked on the ground. This paint when weathered should not increase its reflectivity to more than 8%, which is excellent in the air. The limits of 6% to 8% are not believed to be too critical. (Hexter, 1944, p. 12)

To preserve special markings and finishes, it is necessary to locate them so that they are not applied over transparent material or other areas exposed to extreme heat which would scorch or otherwise damage them (cf., T.O. 1-1-4, p. 3-2).

Temporary specialized aircraft exterior finish schemes are especially subject to damage. For example, if they are easy to remove, they may be soluble in water and, therefore, subject to rain erosion. If they are strippable, they may be subject to damage in flight from warm weather softening of the adhesive or from slip-stream exposure to direct wind blast. For example, pressure sensitive films must be applied carefully to avoid wind blast and cannot be used on supersonic aircraft. For the same reasons, application procedures may be unduly restrictive as to temperature tolerances. For example, film cannot be applied or removed at temperatures below 50° F. Temporary finishes such as films may be more subject to attack by certain lubricants, oils, fuels, and hot exhaust gases. Therefore they may neither serve to protect the surface nor serve to provide a selected special coloration scheme.

Temporary coatings are described in Military Specification MIL-C-6799, Coating Sprayable, Strippable, Protective. For the special application of temporary camouflage of a conspicuity system using fluorescent paint, Military Specification MIL-P-6884 is appropriate, since it can be removed with mineral spirits without seriously affecting the fluorescent system.

Aircraft Surface Integrity

A major reason for applying an exterior finish to aircraft is to provide additional protection to the metal exterior surfaces from corrosion. The standard exterior finish, at ambient temperatures which do not exceed 350° F, is described in Military Specification MIL-L-19537, Lacquer, Acrylic-Nitrocellulose Gloss for Aircraft Use (ASG), which is replaced for camouflaged aircraft by Military Specification MIL-L-19538, Lacquer: Acrylic-Nitrocellulose, Camouflage (For Aircraft Use). The first of these is a glossy paint; the second, for camouflage purposes, is lusterless. Comparable colors are available in the two exterior finish systems.

For ambient temperatures above 300° F, in the range of 350° F to 500° F, a special finish is needed to prevent corrosion of metal exterior surfaces. This is described in Military Specification MIL-E-5557, Enamel, Glass, Heat Resisting, Type I, Black, No. 17038. To provide high heat protection, this finish must be of high contrast and so should be applied on minimum required areas.

A special acid and alkali resistant coating is required in areas where spillage of these materials is expected; this acid-proofing finish is described in Military Specification MIL-C-7439, Coating, Elastomer.

In general, to serve their surface protective purposes, these finishes must be applied according to instructions for preparation of the surface, application of the finish, and routine inspection, cleaning, and touch-up of the finishes after they are applied. Further, they will not, of course, protect the surface from other improper maintenance practices, such as scratching or gouging the skin in the course of applying these and other over-all finishes and markings.

An important special case of protection, of the aircraft surface, which may limit the use of special camouflage or conspicuity exterior finish schemes, is the need for a thermal resistant finish for aircraft programmed to participate in thermonuclear tests. This special finish also limits the use of other special schemes, such as aircraft marking schemes,

which should not be applied over the thermal resistant finish, in certain cases. Of course, authorization procedures for this special finish and for related finishes and markings are required. The finish for use in thermonuclear tests is described in T.O. 1-1-4.

Aircraft Structural Integrity

Damage to the aircraft structure may occur, for example, because of improper use of aircraft surfaces as walkways. Thus, special markings for walkways are required, as is discussed below.

Aircraft Operational Integrity

The exterior finish selected for a particular scheme must be evaluated with respect to its possible interference with the operational capabilities of the aircraft. For example, special markings, such as the National Star Insignia, should not extend over movable flight control surfaces (cf., T.O. 1-1-4, p. 3-2).

When a special aircraft exterior finish scheme is applied over the normal scheme, the added weight must be considered as to its possible effect upon such performance characteristics as speed. Hexter (1944) concluded that this effect of added weight has been greatly exaggerated as a criticism of such special paint schemes as camouflage exterior finish schemes. He calculates that the weight of camouflage paint on a typical fighter aircraft is 17 pounds and that the total weight of all paint is 25 pounds; therefore, the weight price of camouflage is small if the effect of the camouflage is to provide added protection from enemy detection. Also, he points out that paint is needed for some areas for corrosion prevention and that camouflage paint can serve this purpose as well as can other paints.

Certain paints used for camouflage purposes have a rough surface that may produce a speed loss by causing a drag effect. The drag effect is greater for aircraft which operate at higher speeds and is greater for aircraft whose surfaces are otherwise aerodynamically clean, that is, free of mushroom rivets and the like on important surfaces. Hexter (1944) summarized these interactions, as follows:

> In light of present knowledge on the subject it would appear that rough camouflage can retard the top speed of a fighter airplane in the 350 mph class as much as

> 25 mph. Smooth paint is of doubtful value on the slower airplanes such as the heavy bombers where the aerodynamic surfaces are not as clean. (p. 18)

To restore the speed loss, sanding and then rubbing with pumice and water will smooth rough camouflage paint without increasing luster. Waxing to reduce surface drag has been found in flight tests not to improve aircraft speed if the camouflage is smooth and may reduce the speed in warm weather, since some waxes are thermo-plastic (Hexter, 1944, p. 19).

The weight of the finish is important, also, in the problem of maintaining propeller and rotor balance. This subject is taken up, further, below, in the discussion of propeller and rotor finishes and markings.

Comfort, Health, and Safety

It can be assumed or, better, it should be checked that standard personnel safety and health protective work procedures are applicable if standard materials and methods are used. The adequacy of the standard Fleet maintenance workplace environment should be checked as to its comfort and performance of maintenance personnel.

The comfort, health, and safety of the pilot, crew, and passengers of the treated aircraft during operations is, in part, related to maintenance procedures, such as the type of exterior finish to use, special washing procedures, and the like. The performance of the pilot is, of course, critical as a criterion in selecting particular materials for aircraft exterior finish schemes.

Military documents are available giving instructions on these problems, for example, the following:

T.O. 42A-1-1, Health Promotion of Personnel Engaged in Doping and Painting

T.O. 00-110-1, Decontamination (TM3-220)

Anti-Glare Exterior Finish

To avoid objectionable glare to the pilots and the crew, aircraft exterior surfaces within their visual field are finished with a special purpose anti-glare finish, for example, Color Code 37038, "lusterless black," described in Military Specifications MIL-E-5556 for enamel and MIL-L-19538 for lacquer. For each aircraft, the specific location of the anti-glare marking must be standardized by stated authority.

The general location may be stated as "top of fuselage in front of cockpit," For certain aircraft, no such marking is required. For other aircraft, special structures may require anti-glare markings, e.g., forward of aft radome, inboard nacelles, around cockpit, on inner 180° of tip pods, etc. (cf., T.O. 1-1-4, pp. 2-1A, 3-16 through 3-119). The use of paint that can perform this function will, of course, affect the visual range of the aircraft in some situations.

Solar Resistant Exterior Finish

To reduce cabin temperature due to solar heat, a white cap may be painted on the top surface of the cabin hull. The use of solar resistant finish is subject to authorization by major command regulations and is applied only to those aircraft used primarily as personnel carriers.

The configuration used by the USAF is as follows:

> 2-10. SOLAR RESISTANT FINISH.
>
> .....
>
> c. The solar resistant finish shall be separated from the adjacent finish by a three-inch blue stripe. The upper edge of the stripe shall extend parallel to the fuselage reference line from a point approximately tangent to the lowermost edge of the pilot's compartment windows aft to infinity. It is permitted to break the continuity of the straight line in the extreme aft section for esthetic purposes.
>
> NOTE
>
> Aircraft presently painted with a configuration other than above shall not be stripped or repainted solely to

comply with these instructions; however, when initial requirements for solar resistant finish exist or when complete painting is required, the above standard configuration shall be applied.

d. The authorized paint material for use on unpainted aircraft and aircraft presently painted in accordance with paragraph 2-2 is MIL-L-19537, acrylic nitrocellulose lacquer, color, white, No. 17875 and color, blue, No. 15045 for the separation stripe. MIL-E-7729 enamel may be used only on aircraft presently painted with an enamel system still in good condition. (T.O. 1-1-4, pp. 2-1A to 2-1B)

Safety Markings

Certain aircraft details require special finishes and markings to notify both maintenance and operational personnel of dangerous situations. Examples of such special safety markings are the propeller and rotor markings which include markings on the aircraft interior beside any normal or emergency exit. In general, such markings must be preserved regardless of the exterior finish scheme, although they may be modified somewhat. Specific finish and marking schemes for various aircraft details are discussed in Military Specification T.O. 1-1-4.

Supply

It is preferable to select those particular materials that will simplify supply procedures, such as requisitioning and stocking. This is a major argument for using standard materials. It also is a major reason for reducing the variety of materials included in the final form of the aircraft exterior finish system.

For the system finally adopted, supply information should be given as to the materials that will be needed to comply with the system and as to responsibility and procedures for supplying these materials. For each type of material, the standard name and descriptive specification should be stated. Where possible, the quantity of each type of material that will be required should be predetermined; at least, the quantities in which the material is available should be stated. The uses within the system of each type of material should be briefly stated, for reference to detailed maintenance instructions.

Selection and Training of Personnel

If standard materials and methods are used, Fleet maintenance personnel will be equipped by their selection and training to perform any maintenance tasks required by new aircraft exterior finish schemes. Therefore, further human engineering development of specialized personnel selection and training procedures will not be necessary. However, it would be necessary to assess the effectiveness of the supporting equipment, to be developed in this research program, for brief on-the-job training and for routine instruction in the particular maintenance procedures associated with any new exterior finish scheme.

Relevant Military Publications

Air Force-Navy Aeronautical Bulletin 157,
Colors; List of Standard Aircraft Camouflage.

Air Force-Navy Aeronautical Bulletin 166,
Colors; List of Standard Aircraft Glossy.

Federal Standard 141,
Paint, Varnish, Lacquer, and Related Material Methods of Inspection, Sampling, and Testing.

Federal Standard 595,
Colors.

Federal Specification TT-P-54,
Coating, Compound Phosphorescent.

Military Specification MIL-C-5462,
Cover; Wing and Tail, Aircraft, General Specification for.

Military Specification MIL-C-5778,
Covers, Aircraft Components.

Military Specification MIL-C-6799,
Coating, Sprayable, Strippable, Protective.

Military Specification MIL-C-7439,
Coating, Elastomer.

Military Specification MIL-C-27315,
Coating Systems, Elastomeric, Thermally Reflective and Rain Erosion Resistant.

Military Specification MIL-D-8634,
Decal, Elastomeric Pigmented Film, For Use on Exterior Surfaces.

Military Specification MIL-D-8634B,
Decalcomanias.

Military Specification MIL-E-5556,
Enamel, Camouflage.

Military Specification MIL-E-5557,
Enamel, Glass, Heat Resisting, Type I, Black, No. 17038.

Military Specification MIL-E-5558,
Enamel; Wrinkle-Finish, for Aircraft Use.

Military Specification MIL-E-7729,
Enamel, Gloss.

Military Specification MIL-F-7179,
Finishes and Coatings: General Specifications for Protection of Aerospace Weapons Systems, Structures and Parts.

Military Specification MIL-F-18264,
Finishes; Organic, Aircraft; Application and Control of.

Military Specification MIL-F-22735 (WEPS),
(conspicuity arctic marking film kit)

Military Specification MIL-H-24148 (SHIPS),
Human Engineering Requirements for Bureau of Ships Systems and Equipment.

Military Specification MIL-L-6805,
Lacquer - Camouflage.

Military Specification MIL-L-7178 (TT-L-32),
Lacquer, Cellulose Nitrate, Gloss, for Aircraft Use.

Military Specification MIL-L-19537,
Lacquer, Acrylic-Nitrocellulose Gloss for Aircraft Use (ASG).

Military Specification MIL-L-19538,
Lacquer; Acrylic-Nitrocellulose, Camouflage (For Aircraft Use).

Military Specification MIL-L-25142,
Luminescent Material, Fluorescent.

Military Specification MIL-P-6884,
Paint, Temporary, Gray, No. 36231.

Military Specification MIL-P-21563,
Paint System, Fluorescent, for Aircraft Application.

Military Specification MIL-P-38477,
Decalcomanias.

Military Specification MIL-T-9906,
Tape, Pressure Sensitive.

NAVSHIPS 94324,
Bureau of Ships, Design Criteria for Maintainability.

Technical Manual T.O. 1-1-1,
Cleaning of Aeronautical Equipment.

Technical Manual T.O. 1-1-2,
Corrosion Control and Treatment for Aircraft and Missiles.

Technical Manual T.O. 1-1-4,
Exterior Finishes, Insignia and Markings Applicable to Aircraft and Missiles.

Technical Manual T.O. 1-1-8,
Application of Organic Coatings (Paints and Allied Materials).

Technical Manual T.O. 1-1-25,
Inspection of Fabric Covered Surfaces.

Technical Manual T.O. 1-1A-11,
Engineering Handbook Series for Aircraft Repair - Fabric Repair and Doping.

Technical Manual T.O. 42A-1-1,
Health Promotion of Personnel Engaged in Doping and Painting.

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THE PSYCHOLOGICAL LITERATURE, RELEVANT TO DEVELOPING MILITARY AIRCRAFT SURFACE CAMOUFLAGE SCHEMES TO MINIMIZE VISUAL DETECTION, IDENTIFICATION, AND/OR ESTIMATION RANGES UNDER VARYING CONDITIONS, IS SURVEYED. THE SURVEY CONSIDERS BRIGHTNESS, HUE, SATURATION, SPATIAL, TEMPORAL, AND MOVEMENT JUDGMENTS AND FACTORS THAT AFFECT ATTENTION. SPECIAL ATTENTION IS GIVEN TO PREDICTION PROBLEMS, SPECIFIC AREAS REQUIRING FURTHER RESEARCH, AND CONTROL AND MAINTENANCE FUNCTIONS.

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